

PLANNING FOR FOREST ROADS--STATE OF
THE ART IN CORRIDOR SELECTION

Reuben N. Weisz, David A. King, and
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In Partial Fulfillment of:

Eisenhower Consortium Cooperative Agreement 16-447-CA

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PREFACE

This survey of the literature is one part of a final report for a study entitled "Development of a Corridor Selection System for Forest Road Location Planning." The study is primarily directed towards problem area 5 of the Eisenhower Consortium Charter in that it concentrates on the need to " . . . develop new or modified systems to enable large numbers of people to move to, through, within and from wildland areas with minimal environmental impact." The investigators in this study believe that new or modified systems of transportation planning are needed to solve this problem.

Too often, transportation systems analysis has been expressed in terms such as volume, design speed, capacity, structures, and horizontal and vertical alignments with little or no attention given to impact on natural systems. Even where the result has not been a spurious cost-benefit analysis, there seems to be a tendency to relegate environmental impacts to an ancillary role.

One aspect of the problem that is relevant from an environmental management point of view is the process used to formulate and evaluate alternative locations and configuration patterns for transportation corridors in forest road location planning. Computer based land use planning models could provide the planner with a valuable analytical tool for the selection of socially desirable corridor location alternatives.

This publication describes the state of the art in corridor selection. Chapter I introduces the reader to existing Forest Service laws, guidelines and procedures that are related to road location planning. Corridor

selection studies that were not conducted in the context of forest road location planning are the subject of Chapter II. Chapter III contains a review of the literature that is related to the corridor selection problem but that does not deal with the corridor selection problem directly. Chapter III completes the survey of the literature phase of this study.

A subsequent publication will document the procedures and experimental results developed in the test application of our methodology. It will also critically examine the feasibility of using the methodology in U.S.F.S. transportation planning.

This research represents the findings, conclusions and independent judgment of the researchers. Their views should not be construed as necessarily representing those of the Forest Service.

CHAPTER I

EXISTING FOREST SERVICE LAWS, GUIDELINES AND PROCEDURES

As is the case for any major activity in human culture, forest road planning takes place within the context of a complex society, and a framework of laws. It is beyond the scope of this paper to describe that context. Interested readers are directed to the extensive bibliography, for references discussing many of the salient issues. It is even inadvisable to detail the content and the history of all the laws relating to the U.S. Forest Service. That has been done well in Agricultural Handbook No. 453, The Principle Laws Relating to Forest Service Activities (1974), and FOREST--Goals and Decisionmaking in the Forest Service by Richard M. Alston (1972). However, a broad outline of selected provisions of major laws will be discussed.

Legal Background of the Forest Service

Following the "Creative Act of 1891" (Title 16, United States Code, Section 471) which gave the President authority to set up national forest, the Organic Administration Act of 1897 (Title 16, United States Code, Section 475) laid out the terms:

"All public lands ... set aside and reserved as National Forest ... shall be as far as practicable controlled and administered in accordance with the following provisions. No National Forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flow and to furnish a continuous supply of timber for the use and necessities of citizens of the United States; but it is not the purpose or intent of these provisions or of the Act providing for such reservations, to authorize the inclusion therein of lands more valuable for the mineral therein, or for agricultural purposes, than for forest purposes ... The Secretary of Agriculture shall make provisions for the protection against destruction by fire and degradation upon the public forests and National Forests ... and he may make such rules and regulations and establish such service as will insure the objects of such regulations, namely, to regulate their occupancy and use and to preserve the forest therein from destruction ..." (quoted in Alston, p. 13).

The emphasized passages have been used by some to indicate the priority of timber and waterflow protection over other purposes such as grazing and recreation. Some court decisions up until 1952 supported this claim. However, with changing conditions, judicial interpretation also changed and evolved. In the 1965 case, McMichael and McMichael vs. United States (355 F 2d 238, 1965) the court found that although timber and water purposes are required for the creation of a National Forest, nothing in the 1897 Act prevents other considerations from being included, or even given higher priority in the administration of the forest.

In the years before 1960, numerous laws were enacted that enlarged and clarified some of the responsibilities of the Forest Service. Authority was given to acquire lands, to research the best methods of "growing, managing, and utilizing timber, forage, and other forest products" including the economic considerations of management, to require deposits from logging companies to cover costs of reforestation, and to form "sustained yield units" to promote continuous supplies of timber. Most of these however, still emphasized the watershed and timber activities, with only passing mention to other purposes. Despite the lack of legislative emphasis, other uses were permitted, and many recognized the interrelationships. Gifford Pinchot, the first head of the Forest Service, wrote in 1905:

"In the administration of the forest reserves it must be clearly borne in mind that all land is to be devoted to its most productive use for the permanent good of the whole people, and not for the temporary benefit of individuals and companies. All the resources of forest reserves are for use and this use must be brought about in a thoroughly prompt and business-like manner, under such restrictions only as will insure the permanence of these resources." (Alston, p. 18)

And in 1929, the Secretary of Agriculture wrote: "National Forest Administration...aims at the coordinated development and use of all the forest resources, including recreational and wildlife resources." (Alston, p. 20). These ideas grew within the Forest Service over the years, and finally came to fruition in the Multiple Use-Sustained Yield Act of 1960 (Title 16, United States Code, Sections 528-531).

This law specifically listed the purposes of National Forest administration as "outdoor recreation, range, timber, watershed, and wildlife and fish purposes." Further, the above products are to be managed for "multiple use and sustained yield." "Multiple use" is defined as the "management of all the various renewable surface resources of the National Forests so that they are utilized in the combination that will best meet the needs of the American people ... and with consideration being given to the relative values of the various resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output." And "sustained yield" means "the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the National Forests without impairment of the productivity of the land."

The Multiple Use-Sustained Yield Act clarified the purposes of the National Forests, and emphasized and reiterated their permanent nature, to be protected from "destruction and depredation." With the passage of the National Environmental Policy Act of 1969 (NEPA, 42 U.S.C. 4321 et seq.) the basis for consideration of noneconomic values was strengthened, as was the role of environmental information in decision-making: "... all agencies of the Federal Government shall ... identify and develop methods and procedures ... which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision-making

along with economic and technical considerations ... and (all agencies shall) initiate and utilize ecological information in the planning and development of resource-oriented projects." These provisions, plus the mandates to develop alternative plans and to submit environmental impact statements on "proposals for legislation and other major Federal actions significantly affecting the quality of the human environment" present a model for decision-making whose strict procedures have been consistently upheld in the courts. (See Anderson, NEPA in the Courts, 1973, 1974 for a complete discussion.)

The Forest and Rangeland Renewable Resources Planning Act of 1974 makes the following statement: (16, U.S.C.A. 1601 et seq. 533)

(b) In the development and maintenance of land management plans for use on units of the National Forest System, the Secretary shall use a systematic interdisciplinary approach to achieve integrated consideration of physical, biological, economic, and other sciences.

The Planning Act also requires the Secretary of Agriculture to prepare an annual report for Congress each year. The report is described in the following words: (16 U.S.C.A. 1601 et seq. 535)

The report shall contain appropriate measurements of pertinent costs and benefits. The evaluation shall assess the balance between economic factors and environmental quality factors. Program benefits shall include, but not be limited to, environmental quality factors such as esthetics, public access, wildlife habitat, recreational and wilderness use, and economic factors such as the excess of cost savings over the value of foregone benefits and the rate of return on renewable resources.

As stated in the introduction to this report, the authors of this paper are developing and testing a "systematic interdisciplinary approach" to corridor selection that can be used to "assess the balance between economic factors and environmental quality factors". We believe that this study is being conducted within the letter and spirit of existing Forest Service laws, guidelines and procedures.

Implications of the forest laws for management

After a lengthy analysis of the legislative history of the Forest Service, Alston (1972) proposes that the goal which the Service is directed to achieve is to maximize the total value of the National Forests. That is, the Service must maximize the sum of the weighted values of "outdoor recreation, range, timber, watershed, and wildlife and fish" (Multiple Use-Sustained Yield Act). Because of the interrelationships of these elements, the goal is not necessarily to maximize any one element's value, but to be concerned about the sum total. This objective function is then constrained by the considerations of permanent productivity (total productive capability in the future may not be less than the capability today); sustained yield (the rate of growth of renewable resources in the future must at least equal the rate today, and cannot be exceeded by the periodic harvest of the resource); and budget restrictions (expenditures on each resource cannot vary more than seven percent from the amount budgeted, and the sum of all expenditures cannot exceed the total budget).

The constraints are relatively straightforward, but the objective function, the goal of the Forest Service, is faced with a number of operational difficulties. One problem is that each of the total outputs of each forest resource should be expressed in the same terms within one particular resource. This may not be difficult in the case of economic outputs such as timber or forage--the final units can be the dollar value of total output. But the other forest resources have no easy conversion to the common value units of dollars. Is one person-day of camping worth the same as one person-day of boating, or is a one percent increase in the bear population equivalent to a one percent rise in the number of deer? An even more difficult question is what are the proper priorities or weights that should be assigned to the resource outputs once quantified? The legislation names

no priorities, although Alston reports that Forest Service budget requests and Congressional appropriations have reached a momentary equilibrium in terms of percentage of the Forest Service budget allocated to each resource program. Even so, Forest Service headquarters priorities differ from the Congressional decisions, as shown by the 90 to 97 percent of budget request approval by Congress for range and timber resources, with only 67 to 79 percent approval for watershed, reforestation, recreation, and wildlife programs. In addition, there are other values and priorities to be considered. Each forest has its own unique conditions, and the staff, the forest users, and the local residents all have individual preferences and priorities regarding the forest's development and use. Which priorities are to be used in the facility design decision process, and how are those used to be weighted and summed? Some approaches to this dilemma will be discussed in later portions of this report, but it is evident that the systems analytic approach to forest road planning must come to grips with the problems of multiple value systems in order to solve the design problem.

Much progress has been made in systematic studies of interactions between resource elements. This, of course, is an essential first step, for while values can be formed and implemented without much information, the results of actions taken in their behalf are not likely to be satisfactory. Some of these studies listed in the bibliography include Bird (1973), Bower (1971), Brown (1971), Clawson (1974), Cox et al. (1972), Daniel et al. (1973), Detwyler (1971), Elsner (1974), Feuchter and Wingle (1973), Fredrickson (1970), J.R. Jones (1971), Kaiser et al. (1972), Kidd and Kochenderfer (1973), Krammes and Burns (1973), Kunit and Calhoun (1973), Leaf and Brink, Lyle and von Wodtke (1974), Mehagan and Kidd (1972), E. P. Odum (1971), Patric (1973), Pfister (1969), Spurr (1974), and others.

With increasing knowledge and appreciation of the complex interactions taking place, integration of the information into

a unified system has been a major goal. Daniel Chappelle in "Quantitative Analysis in a Qualitative World: Modeling Forestry Systems to Improve Decision Making" (Stone and Ware, 1972) discusses some of the problems facing the would-be systems modeler. First, as mentioned before, values and priorities have to be taken into account. Chappelle feels that the distinction that some modelers make between "priced" and "non-priced" goods in forest planning is spurious, since no free market exists even for products such as timber--the price is an administered one, and is dominated by spatial monopolies and oligopolies. Thus, he proposes that models must explicitly incorporate the relationships of organizational structures, diverse goals, imperfect communication, and uncertainty in order to effectively simulate reality.

Other problems that must be faced are 2) existing models of many sub-systems are still in a primitive state; 3) controllable variables are not always included in existing models; 4) all linkages in the decision process are not known; 5) the time and space frameworks vary widely for various forest products; 6) a good transportation sub-model needs to be developed; and 7) the factors of land ownership and biological gradients need to be included. Because of these problems, and "the high degree of complexity involved in forestry decision systems, the high degree of uncertainty, the long production period for timber, the lack of quantification of many of the variables, and the fact that many decision processes defy modeling in mathematical terms," Chappelle suggests the use of a human interactive model. Use of computers within the sub-models would be expanded, but man would be relied upon for "nonprogrammed" decisions. He also feels that more use should be made of qualitative, nominal and ordinal scale data, rather than always relying on quantitative data that seems to be in short supply.

Additional changes that Chappelle advises include efforts by the modelers to create models for the use of decision-makers rather than the approbation of other scientists, and revisions of the existing institutional structure to improve the decision process.

Since 1971 when Chappelle delivered his paper, some progress has been made toward the goal of improving the decision-making process. An example is the sub-model created for the nation's range resources, presented in Forest-Range Environmental Production Analytical System, (FREPAS).

(Kaiser, DeBower, Lockard and Putnam, 1972). FREPAS is a linear programming (L.P.) model designed to "find the optimum set of factors (planning, investment, management and maintenance costs) under alternative strategies for the use of forest-range resources in achieving alternative goals for grazing and related social and environmental values." (Kaiser et al., p. 1).

The variables necessary to implement this model are the following:

- 1) Land inventory--characterized by
 - a) ecosystem type (40 different classes),
 - b) ownership (3 classes--National Forest, other Federal, and other),
 - c) and, by productivity (4 classes) and condition (3 classes) for both forest and range ecosystems.
- 2) Management strategies
 - a) Environmental management without livestock,
 - b) Environmental management with livestock,
 - c) Extensive management of environment and livestock,
 - d) Intensive management of environment and livestock,
 - e) Maximum management of environment and livestock,
 - x) Management at a substandard level (necessary to categorize some existing conditions and for predicting their consequences).
- 3) Practices--18 control measures that could be taken, from fertilization to timber thinning.
- 4) Costs--annual costs plus interest of each of the practices.
- 5) Products--goods and services obtainable from forest and range lands. The 22 products are divided into two categories: 9 of them easily quantified, ranging from tons/acre of browse and herbage produced to man-hours/acre of employment; the other 13 are qualitative estimates, scored on a scale of 1-5 (1 = bad, 5 = excellent) and ranging from soil stability through beauty to flexibility for future management.

6) Land use--with four conditions:

- a) Now situation: existing percentage of land managed under each management strategy.
- b) Now policy: percentage of land under each strategy if present policies were followed until the year 2000.
- c) Maximum: "reflects the physical and biological limits that can be expected to fall within each strategy on a particular resource unit" (geographic area).
- d) Minimum: "reflects laws, economic and institutional restraints, and policies which require application of a certain strategy."

and 7) Goals--A grazing goal (product value) is first chosen and optimized. Then additional quantitative goals are added successively and their effects studied, both on the other quantitative products and on the qualitative indicators. The essence of the system is the analysis of change under alternate goals.

Of course, data for all of the variables must be collected, coded, and input into the computer, undoubtedly a lengthy process. Once input, however, the data is manipulated by four programs:

- 1) FLIPS--the basic data handling program, which does data conversion, editing, and summarizing, and produces the output tapes necessary for the next step, MATGEN.
- 2) MATGEN--puts the data into the proper format for the next program, the LP Model.
- 3) LP Model--this program minimizes the costs of investment for range management, subject to the acreage limits and product output requirements (goals).
- 4) REPGEN--summarizes the results and puts them into a report table form useful for decision-making. The output tables include
 - a) acreage by ownership, productivity/condition, for all strategies used;
 - b) product totals and production/acre for each strategy;
 - c) detailed cost totals for each strategy used; and
 - d) acreages for each practice and strategy, and also the total costs for each.

Of course, the usefulness of the FREPAS model is not fully apparent with just one run of the program sequence. Its most important characteristic is its ability to test the sensitivity of the solutions generated to changes in costs, requirements, and goals. Thus, not only can the effect of uncertainties in certain variable values be evaluated, but also the output can show the results of changes over time.

Another example of work being done to improve the decision process is entitled "Comprehensive Land-Use Planning" (Torheim and Harland, 1973). In this case, however, the emphasis is on organizational changes, rather than the mathematical model of FREPAS. The authors first discuss the drawbacks and narrow viewpoints of "functional planning" for timber,

recreation, wildlife, and other programs, as practiced by the Forest Service in the 1950's. As the interrelationships between the functional areas became apparent in the 1960's, multidisciplinary planning teams were assembled. These usually consisted of a forester, engineer, landscape architect, biologist, and a soils scientist or hydrologist, plus consultants in fields such as sociology and geography as needed. Despite the added breadth of knowledge and experience provided by the multidisciplinary team, it has become evident that many critical interactions are still being neglected. A National Forest does not exist in a vacuum--it is surrounded and affected by the values and plans of other Forest Service regions, the private land-owners nearby, and other governmental agencies at all levels. Unless forest planning takes these interactions into account it will not be effective.

The authors propose an organizational plan to deal with these problems. The basic framework is shown in Figure 1," (from Torheim and Harlan, p. 469).

In this process, communication skills will be essential, for those in the planning team will be dealing not only with other resource experts, but also with other agency personnel with different areas of expertise, consultants from universities, local elected officials, and interested private citizens. The authors feel that cooperation between Forest staff and Experimental Station personnel would be beneficial to both --"the scientist will become better acquainted with field problems, and the land manager more responsive to applying research results," (Torheim and Harlan, p. 470).

To accompany this new structure for decision-making, the authors propose a new approach to budgeting. Instead of the money coming down from above to be divided up among the various regions and forests, Torheim (deputy regional forester, Pacific Northwest Region) and Harlan believe that forest supervisors and their district rangers should determine the goals and tell

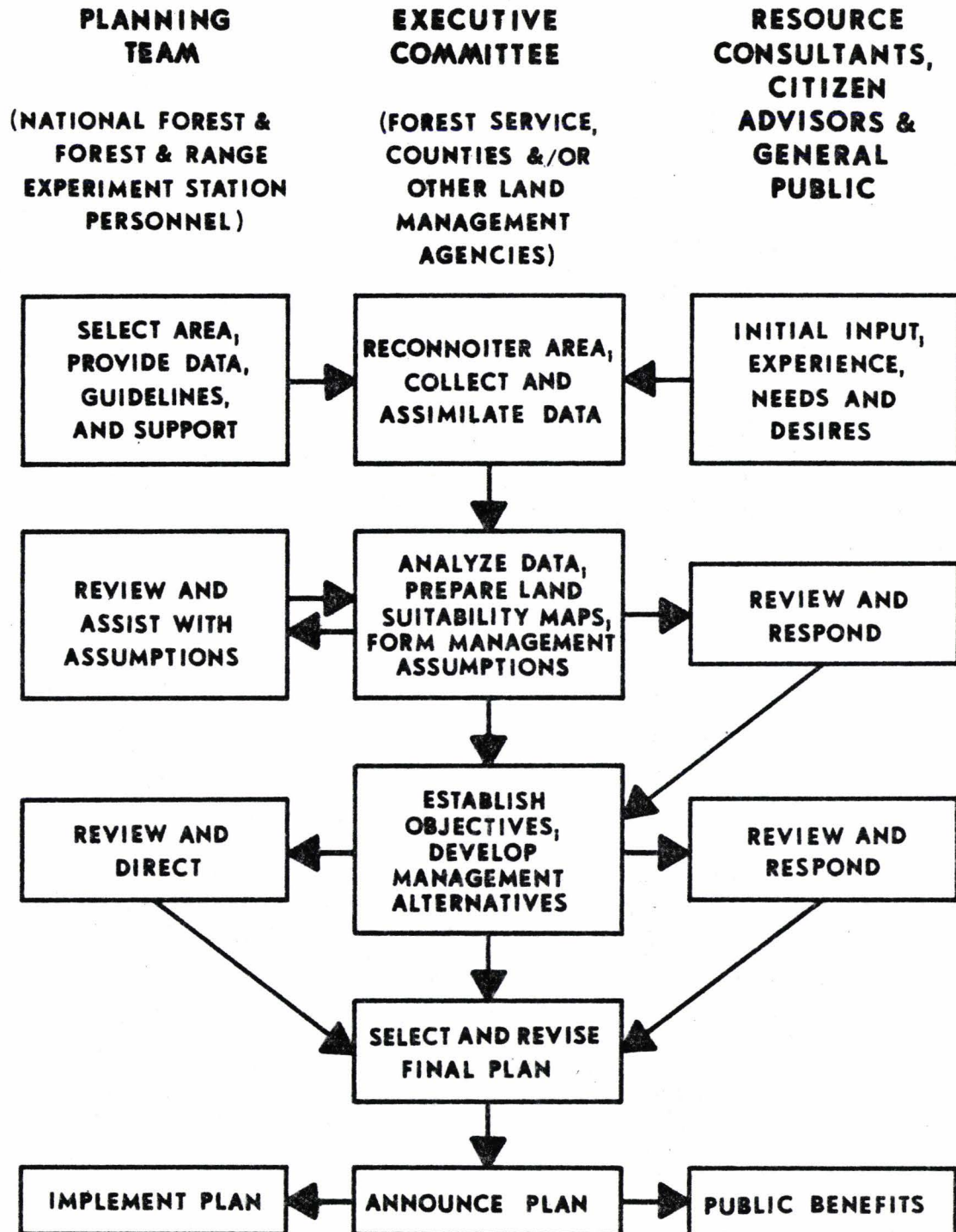


Figure 1

Proposed Organizational Framework for
Comprehensive Forest Planning

the regional forester what they can do with a certain level of manpower and funding. After negotiations, the final agreement is sent to Washington, where it is modified by Congressional or executive budget priorities. How the appropriations pie is divided up once it reaches the regional level again is unstated, but presumably each forest receives the same percentage of the appropriation as it had in the original budget request.

Carder and Golesby (1973) describe what is essentially the same process as that outlined by Torheim and Harland, Unified Planning and Decisionmaking: A Conceptual Framework for Forest Service Management.

This document reflects current Forest Service thinking on the subject.

Specific laws relating to forest road planning

In addition to the general laws directing the Forest Service, some specific legislation has been enacted concerning the building of forest roads. One of these was the National Forest Roads and Trails System Act of 1964, 78 Stat. 1089, 16 U.S.C., Secs. 532 and 535. (See U.S.D.A., Agricultural Handbook No. 453, 1974). It reads in part:

"The Congress hereby finds and declares that the construction and maintenance of an adequate system of roads and trails within and near the national forests and other lands administered by the Forest Service is essential if increasing demands for timber, recreation, and other uses of such lands are to be met; among other things, of increasing the value of timber and other resources tributary to such roads; and that such a system is essential to enable the Secretary of Agriculture (hereinafter called the Secretary) to provide for intensive use, protection, development and management of these lands under principles of multiple use and sustained yield of products and services." (16 U.S.C. 532).

"The Secretary is authorized to provide for the acquisition, construction, and maintenance of forest development roads within and near the national forests and other lands administered by the Forest Service in locations and according to specifications which will permit maximum economy in harvesting timber from such lands tributary to such roads and at the same time meet the requirements for protection, development and management thereof, and for utilization of the other resources thereof." (16 U.S.C. 535).

In other words, the design of the road system is to minimize the cost of timber harvesting, subject to the constraints of the environment, and the development and management policies.

Other specific laws relating to forest road planning are found in Title 23 of the United States Code (Highways). Section 211 describes the provisions for timber access road hearings:

"With respect to any proposed construction of a timber access road from funds authorized for forest highways or forest development roads and trails, advisory, public hearings may be held at a place of convenience or adjacent to the area of construction with notice and reasonable opportunity for interested persons to present their views as to the practicability and feasibility of such construction."
(23 U.S.C. 211)

And Section 305 allows for archeological and paleontological salvage:

"Funds authorized to be appropriated to carry out this title to the extent approved as necessary by the highway department of any state, may be used for archeological and paleontological salvage in that State in compliance with the Act entitled An Act for the preservation of American antiques, approved June 8, 1906 (34 Stat. 225), and State laws where applicable." (23 U.S.C. 305).

With the present emphasis on citizen participation and the environment, such provisions will most likely be incorporated into the decision process.

Forest transportation planning procedures

Specific approaches and procedures used for forest road planning have changed and adapted to the times along with overall forest management methods. Thus, it may be instructive to consider where the field has been in order to determine where it should go. A book from the 1950's Applied Forest Management (Bruns, 1954) contains an informative chapter on "Forest Road Planning" by T. A. Walbridge, Jr. In this work, apparently primarily intended for use by private timber companies, the goal of forest road planning was to minimize the sum of road construction cost plus maintenance cost plus log hauling costs, "provided silvicultural standards are met."
(Bruns, p. 146).

One way of reducing construction and maintenance costs is to use public roads as much as possible. However, public roads often have constraints, such as low bridges and vehicle weight limits. If the timber to be transported is large, these constraints may be exceeded, and it will be necessary to build a complete private road system. Another determinant of road costs is the road standard that is chosen for construction. The choice depends on the intended use of the road (dependent upon management purposes and timber size), the desired permanence of the road, its initial cost, future maintenance costs, and the desired speed of hauling desired.

The other major factor in cost calculations is the hauling cost. This is a function of the length of the road and the hauling speed which is in turn dependent upon the grade of the road, its surface characteristics, and its alignment.

Walbridge listed a seven item procedure for the location process for forest roads. The first order of business is given as 1) reconnaissance. This is to be a detailed survey of the study area by means of topographic maps, aerial photos, and personal ground inspection. The object of the survey is to collect useful data on the topics of topography, soils, ownership patterns, timber locations, natural barriers, management policies, and logging methods. Then 2) there is a consideration of the alternate routes generated in Step 1. Consideration is given to comparative grade lines, construction costs, hauling costs, intended use, and desired permanence. If all else is equal, the major factors are the length of road and the grades. Especially critical are the "adverse" grades, the ones the trucks must climb when loaded. Other steps include: 3) choice of grade lines on the selected route; 4) location of the route centerline; 5) land ties to section corners; 6) preparation for construction; and 7) aids to construction.

Of the seven steps listed above, the author feels that all should be used in the planning of forest highways and the smaller "main drainage roads." However, often only steps 1-4 are completed for the drainage roads. Finally, location work for spur or branch roads usually consists of just steps 1 and 3.

Another work entitled "Forest Road Planning (Waelti, 1970) uses many of the same design and location criteria discussed by Walbridge 16 years earlier. However, Waelti emphasizes the use of aerial photography as an analytical tool for forest road planning, especially where the study area is unmapped and inaccessible.

Waelti lists five physical features as the principal determinants of road location, utility and cost. These are 1) the steepness of the terrain; 2) the ruggedness of the terrain; 3) the soil material (composition and depth); 4) drainage pattern and soil moisture regime; and 5) location of control points such as passes, bridge sites, canyons and slides.

Through simple observation of aerial photos, aspects such as vegetational pattern, texture, graytone, erosion pattern, drainage pattern, and topography can be noted. Successive interpretation procedures can then generate data on the forest type, terrain steepness and ruggedness, landform type, occurrence of rock, terrain stability, soil moisture, type and bearing strength, gravel location, quantity and quality, excavation requirements, drainage requirements, and location of control points. Of course, no interpretive procedure such as this is infallible. Areas of uncertainty and the approximate alignment of the road system should be field-checked before making any final decisions. However, the aerial photo interpretation makes the best use of field personnel, by concentrating their work within smaller areas.

The methods outlined in both of the "Forest Road Planning" works

are those of intuitive and experienced engineering judgment. Recently, however, an optimization program has been written to deal with forest road location and spacing. Entitled Optimum Economic Layout of Forest Harvesting Work Roads (Carter, Gardner and Brown, 1973), the program minimizes the total direct cost of road and landing construction, and skidding and yarding operational costs.

Eight separate cost components are considered in this model. They include the cost of (c1) moving in construction equipment; (c2) road planning and layout; (c3) road construction; (c4) switchback construction; (c5) landing construction; (c6) moving in skidding equipment; (c7) skidding equipment set-up; and (c8) skidding. The model is designed to minimize the sum of these component costs.

Data on 32 variables are needed to calculate the various component costs. These variables, and their relationship to the cost components C_1 to C_8 are shown in Table 1 (Carter, et al., p. 7).

The optimum road and landing spacings, as well as the direct cost per thousand board feet (\$/MBF) are then calculated for each construction method, each skidding method, and the use/no use of landings. For an example given in the paper, the optimum result was a road spacing of 675 feet with no landings, and the use of a medium crawler skidder, with a large crawler for construction. Further application of the results is unstated, but presumably the first work road is located manually, with additional roads located every 675 feet. This method appears to depend upon uniform study area characteristics such as sideslope, timber density and log size. Therefore, apparently, for a study area with changing characteristics, several uniform subareas would have to be delineated, and optimization programs devised for each.

Despite the emphasis on direct economic costs shown in the last

Table 1

Variables Related to Eight Direct Costs of Logging Roads

Symbol	Variable Description	Units*	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈
A	Total logging area	acres	x	x				x		
Dc	Constr. method cost	\$/hr.			x	x	x			
Dm	Layout method cost	\$/hr.		x						
Ds	Skidding method cost	\$/hr.							x	x
F	Productivity(constr.)	yd ³ /hr.			x	x	x			
Fm	Productivity(layout)	ft./hr.		x						
Hl	Excavation/landing	yd ³ /land'g					x			
Hr	Excavation/ft. or road	yd ³ /ft-rd			x					
Le	Landing length	feet					x			
Lv	# logs/timber volume	logs/MBF								x
Mx	Maximum road grade	decimal%			x					x
Nc	Move-in cost(constr.)	\$/move	x							
Ns	Move-in cost(skidding)	\$/move						x		
Pc	Product'y coeff.(constr.)	none			x	x	x			
Pm	Product'y coeff.(layout)	none		x						
Ps	Product'y coeff.(skid)	none								x
Ro	% rock in excavation	decimal%			x	x	x			
S	Slope of sidehill	decimal%			x	x	x			
Sp	Time/setup(skidding)	hr/setup							x	
V	Timber volume/hor. area	MBF/acre	x	x	x	x	x	x	x	x
Vc	Volume/skidding cycle	MBF/cycle								x
W	Road width	feet			x	x				
Wl	Landing width	feet					x			
X	Road spacing	feet		x	x	x	x		x	x
Y	Landing spacing	feet					x			x
Zb	Level road/switchback	feet			x					
Zs	Distance between setups	feet							x	
dav.	Average skidding dist.	feet								x
a ₁ to 4	Skidder regression coeff.	none								x

*Key to abbreviations: MBF = thousand board-feet of lumber

y³ = cubic yards of material to be excavated.

three references, the Forest Service Manual (USDA Forest Service, 1973) states that:

"The general location and standards of service roads are influenced more by environmental considerations, than user costs or benefits. These facilities are usually single-lane, design class C or D, and should be planned, designed and built to the standard necessary to accommodate types of vehicles associated with the resource served, while keeping land disturbance to a minimum." (p. 7723--2, emphasis added)

These directions seem to be in accord with the mandate of this project, to develop methods to locate forest roads with minimum environmental impact.

Other useful material is also contained in the Manual, much of it under Title 7700 - "Transportation Systems." Roads are given classifications reflecting the type of traffic they service, when they can be used, their surface type and condition, their drainage characteristics, and their geometric characteristics. These design standards and criteria should prove very useful in the facility design phase of this project. Also helpful will be sample cost calculations for road standard selection, shown in the Forest Service Transportation Engineering Handbook, 1973, pages 12.11 to 12.13.

A broader view of the forest transportation planning process is presented in Transportation System Planning for Forest Resource Management: A Concept (Carder and Mandt, 1971). The authors believe that many important effects of the transportation system upon forest activities, and vice-versa, have been neglected. In addition, transportation system changes affect local and regional land and resource use patterns, and the lives of many residents. They believe that more considerations should be given to aesthetics, relative resource scarcities, and opportunity costs imposed when one action is carried out instead of another.

In the evaluation of alternative plans, Carder and Mandt suggest

the following four steps: 1) A distinction should be made between the responsibilities of the analyst and the decision maker; the analyst should acquire and present information in a way as value-neutral as possible, while the decision-maker will make judgments based upon his or her values; 2) Both internal system and external variables should be considered; 3) The relative merits of alternatives should be evaluated under the conditions of the "most likely" future, then under a range of possible futures; finally, 4) the "worth" of each alternative should be considered, followed by its feasibility.

The authors propose parallel land-use and transportation planning processes, with constant interaction, because of the interactive effects of the two systems. In addition, they call for a better framework for decision-making, in order that the planner can generate more information on possible alternatives and their consequences, and so the decision-maker can assimilate it.

One such framework has been proposed, and is discussed in Transportation Analysis Procedures for National Forest Planning, A Process Overview (Institute of Transportation and Traffic Engineering, 1971). The basic framework itself is nothing new, simply the standard "rational" model of decision-making: 1) Definition of goals and objectives; 2) Information and analytical technique requirement determination; 3) Alternative plans; 4) Data collection and preliminary analysis; 5) Analysis of alternatives; 6) Evaluation of alternatives; and 7) Plan selection, with appropriate feedback loops.

Table 2 (taken from Weisz and Carder, 1975) outlines some of the conceived, developing and/or existing forestry transportation planning systems.

TABLE 2. SOME OF THE CONCEIVED, DEVELOPING AND/OR EXISTING FORESTRY TRANSPORTATION PLANNING SYSTEMS

A. Recreation Models	Allocate traffic to links in transportation network.	
1. Macro-Allocation Model	Predicts travel behavior from large population centers to major forest areas.	
a. Macro-Generation Model	Estimates aggregate quantity of recreation trips that emanate from population center origins.	Regression Model
b. Macro-Distribution Model	Distributes flow of recreationists from origins to destinations across impedance components (transportation links).	Systems Model
c. Macro-Attraction Model	Reduces a large number of characteristics of a forest into a single index of attractiveness.	Factor Analysis
2. Micro-Allocation Model	Predicts travel behavior within an individual forest or study area.	
a. Micro-Generation Model	Estimates aggregate quantity of trips made by population located within the study area forest.	Cross Classification; Analysis of Variance
b. Micro-Distribution Models	Assign trips to links; distribute trips to destinations.	
i. Impedence-Dependent Opportunity Model	Calculates probabilities of trips stopped at destinations based on relative proximity to trips' origin.	Maximum Likelihood Estimation
ii. Simple Proportional	Assumes that number of trips to each destination is proportional to that destinations' attractiveness.	
iii. Touring Travel Model	Estimates traffic flow on links for trips that have no well defined destinations.	Linear Programming
c. Micro-Attraction Model	Develops a single index of attractiveness for each attractor within a forest.	Factor Analysis
B. Timber Transport Model	Assists in computing timber traffic, hauling costs, distances, and time; assists in selecting routes to be used, investments in transportation networks, and timber harvest patterns.	
1. Phase I Sub-model	Considering one transportation-network-timber-harvest-pattern at a time, it generates and evaluates a number of "best" routes between each timber sale node and mill nodes.	Minimum Path Algorithm
2. Phase II Sub-Model	Finds the least cost combination of investment in projects (construction and maintenance costs) and haul routes (operating costs).	Mixed Integer Program
3. Phase III Sub-model	Maximizes the total value of harvested timber minus the associated project investment and haul costs.	Mixed Integer Program

TABLE 2. (Continued)

C. Administrative Travel Model	Selects the most efficient routes and schedule for accomplishing tasks during a number of fixed working days.	Integer Programming Algorithm
D. Fire Protection Model	Finds best location for fire stations on a forest transportation network.	Mathematical Programming
E. Link Analysis Techniques	Focus on a single section of road at a time as opposed to the network analysis techniques described above.	
1. One-lane Road Simulator	Relates link design factors to average speed, travel time, delay and operating cost under congested conditions.	Computer Simulation Model
2. Vehicle Operating Cost Model	Assists in selecting a road design that balances initial construction cost against future operating and maintenance costs.	Computer Model
3. Road Investment Strategy Model	Assists in selecting strategies for construction and maintenance investments in relation to vehicle operating cost and road wear.	
4. Allocating Road Maintenance Funds	Allocates men, money and machines to road maintenance.	Mathematical Programming
5. RDS (Road Design System)	Converts field survey notes and design requirements into information needed to lay out precise road location and to develop construction plans.	Large Number of Related Computational Routines
6. OPTLOC (Optimal Road Location)	Optimizes road location, given origin, destination and other constraints.	Dynamic Programming
F. Transportation Analysis Support Techniques		
1. Transportation Information Systems (TIS) and Road Inventories (TIS-Roads)	This is a system that describes the physical characteristics and geometry of a system of roads and trails using a mathematical model of the transportation network.	Computer Programs and Related Procedures
2. Traffic Surveillance Program	Assists in traffic data gathering, management and statistical analysis.	Handbook and Computer Programs
3. Recreation Interview Survey Data Management System	Assists in gathering information on recreationist travel behavior.	Computer Programs and Related Procedures
4. Decision Making Primer	Techniques for making decisions under uncertainty.	Handbook

CHAPTER II

MAJOR WORKS ON CORRIDOR SELECTION IN OTHER TYPES OF PLANNING

In addition to the useful techniques developed by the Forest Service for its own needs, there are approaches taken in other fields that may prove applicable. Communications in general, and specifically highway and electrical power transmission line planning, deal continuously with problems of network design and corridor location.

Highway planning, in particular, has been a fruitful source for studies of corridor location methods. The reason for this is clear. Not only has the Interstate Highway program provided the ample resources necessary to undertake studies of this kind, but it has also precipitated their necessity. The massive scale and impacts of the Interstate Highways are unprecedented, and demand new, more sophisticated location procedures in order to minimize possibly harmful effects.

Highway Corridor Selection

An excellent example of the new approach in highway planning is An Interstate Corridor Selection Process, by Allen Miller and Bernard Niemann (1973). In it, the authors examine the problem of choosing a location for a proposed Interstate highway connecting Milwaukee and Green Bay, Wisconsin. Their concern was to "show how the location, planning, and eventual construction of a highway can be accomplished with maximum benefit to the public, and minimum harm to the environment." In pursuit of this goal, the interdisciplinary group involved developed a list of nine "determinants" or factors thought to be critical in the corridor location. These included areas of greatest scenic potential, greatest engineering capabilities, least cost of construction and

acquisition, least disruption to the cultural system, to the ecological system and to potential recreation and conservation lands, conservation of quality agricultural land, and projected traffic generation.

Central to the approach of Miller and Niemann to these factors was the desire to make the decision-making process as explicit as possible. For they recognize that corridor selection represents a value judgment, not merely a technical decision, and that the values of those affected by the facility must be clearly and systematically incorporated into the decision process.

Since, at the beginning of such a study, it is difficult to foretell which determinant will be critical, and which values will be most influential in the process, it would seem best to create a study framework which would allow the effects of different variables to vary. That is what was done. Through the data-handling capabilities of the computer, the values of each variable in each of the 9300 one-kilometer square cells in the study area were assembled and stored. In all, values for 129 different variables were collected, including such items as "topographic orientation," "percent of cell that is barren land," "percent of cell that is residential land use," "number of Federal highways per cell," and many others. They were then available for manipulation and combination.

The first such manipulations involved the decision as to which variables affected which determinants. This was done by professional census at an interdisciplinary staff meeting. Variables that had similar influence (such as the effect of varying soil types on engineering capabilities) were grouped into "components" (see Figure 2). The relative importance of each variable in the component was chosen by professional judgment, and each variable given a relative weight. Eventually each weight would be multiplied by the percentage of the particular cell

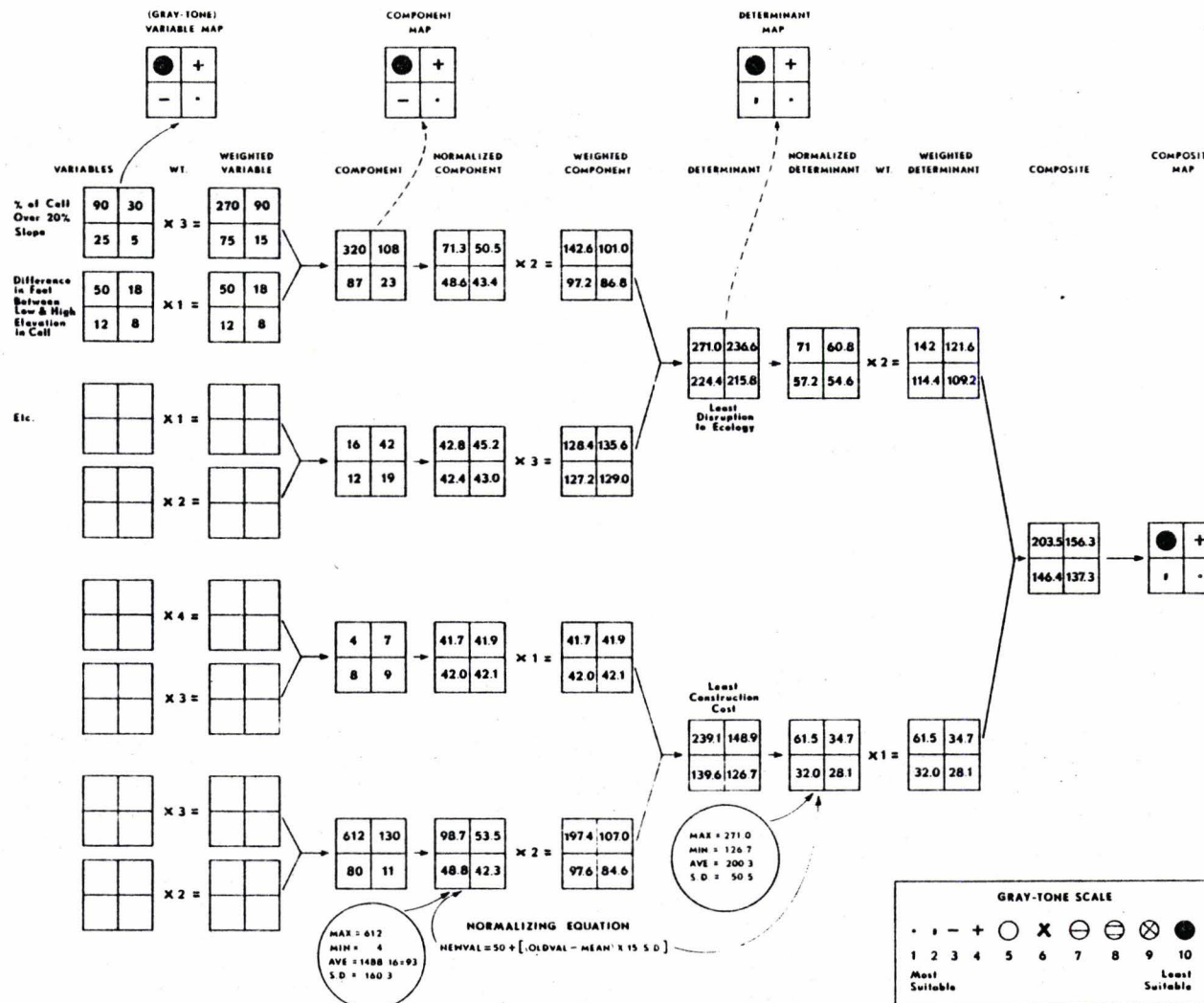


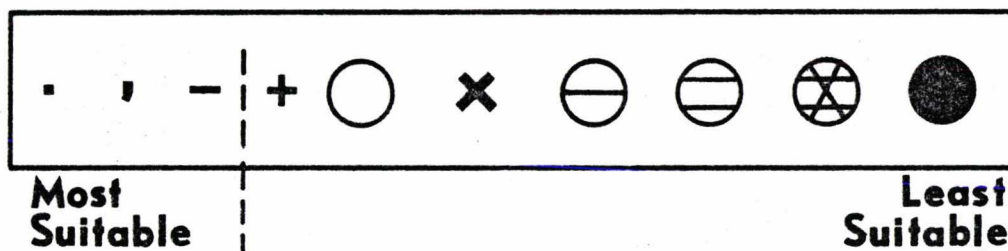
Figure 2
Miller-Niemann Weighting and Mapping Process

devoted to that variable, to produce a component value for the cell. However, due to the wide variation in the numerical ranges produced by the weighting process, comparisons between the components were difficult. In order to achieve some sort of equivalence between components, component values were normalized using a function of the component mean and standard deviation. Then weights for each normalized component were chosen to reflect a judgment on the relative importance of each to the value of the determinant. Totals for each determinant were also normalized to avoid numerical bias, and the final determinant values for each cell were converted into a computer-generated gray-scale map, one for each determinant.

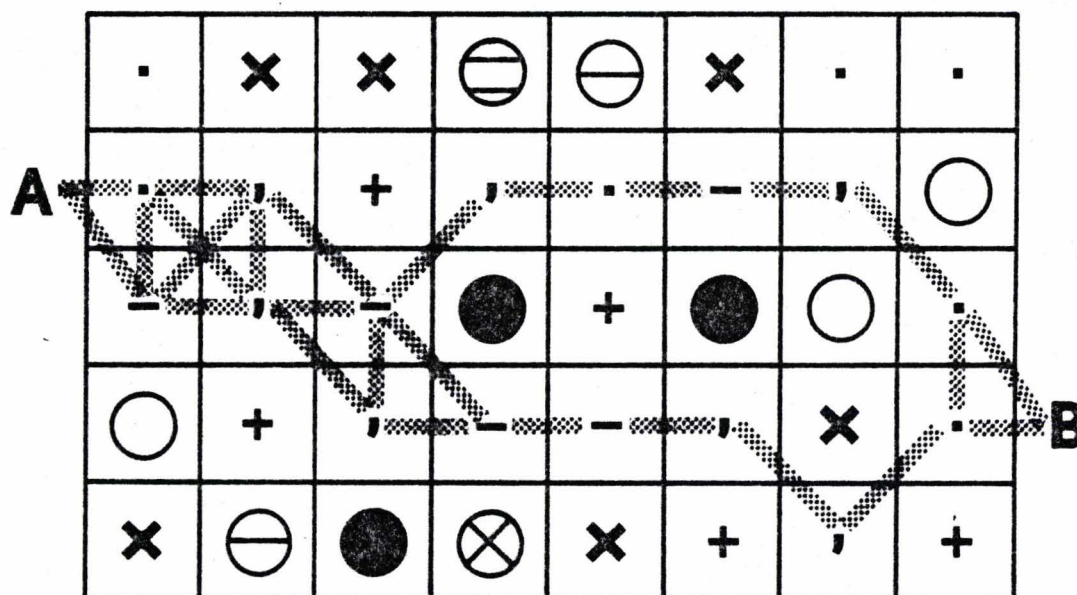
With maps representing each determinant generated, the mapped determinants themselves can be weighted and composited further, to reflect the varying priorities of interest groups and participants. A scheme giving equal weight to each determinant was eventually chosen because of its "objectivity," but sensitivity analysis and congruency/disparity analysis could be used to identify areas agreed to as suitable by "all". Further investigation then could focus on the area of disagreement. With the composite alternative chosen, many potential corridors were manually delineated by selecting a network of cells in the top 1/3 of suitability (see Figure 3). Where connections could not be made by this criterion, the least unsuitable cells were used. Although a manual technique was used for the process in this study, several techniques are available for having the computer do the selection (see E. F. Moore, 1959; B. V. Martin, 1963; and Whiting and Miller, 1960).

For final selection, manual tabulations of corridor characteristics, in conjunction with public hearings were used. For the future, the authors suggest the need for more sophisticated analysis by computer,

STANDARD GRAY-TONE SCALE



EXAMPLE MAP



Alternate routes are drawn by connecting cells containing any of the three "most suitable" symbols.

Figure 3

Delineation of Alternate Routes

including the relationship of the corridor to the various determinants, the relationship to the resources in the study area, the effects of the corridor on the environment over time, and evaluation of the effects of errors in the process.

In their report, Miller and Neiman discussed several existing corridor location methods. One of these is the "Denver Five-Step Process" developed by the Bureau of Public Roads Region Nine in Denver, and applied to highway planning on Federal land. Its approach is described below.

Step 1: Reconnaissance

Service objectives are solicited from land management agencies in the corridor study area. These objectives are then drawn on aerial photo mosaics at 1:20,000 scale, and a corridor drawn for the "most feasible routing that satisfies the service objectives."

Step 2: Control Survey

The proposed corridor is stereo-photoed at 1:6000 scale, and submitted to the land agencies for their evaluation of its impacts. They assign appropriate disciplines to study and annotate the photos, after which they are returned to the highway department for compilation of the comments.

Step 3: Paper Projection

A highway centerline is delineated within the corridor, that "will serve the designated objectives and complement the general physiography without regard to design speed." Once again the proposal is returned to the various agencies for review, followed by a "joint review in the field where 'trade-offs' are made between disciplines."

Step 4: Centerline Staking

The centerline is located on the ground, and participating disciplines are asked to recommend parameters "that will enhance the roadway and provide compatibility with the environment."

Finally, Step 5: Facility Design

Using the above parameters along with the engineering requirements of capacity, safety, stability, and design as constraints, alternative designs are generated by computer. An alternative is then selected, sent to the other agencies, and reviewed in the field. If no other problems surface, construction plans are then begun.

As may be noted, the corridor location process, the subject of the entire report by Miller and Neimann, is covered by the Denver method in only Step one. The remaining four steps are devoted to preparing the optimum facility design for that selected corridor, homing in on the optimum increment by increment. Trade-offs between conflicting professional values do not appear to be systematic or explicit, and even if they were, they would have to be made within the narrow confines of the corridor which was selected in Step one.

Another location methodology cited by Miller and Neimann is that devised by Roberts and Suhrbier of MIT. Their approach to the problem is described in their report Highway Location Analysis: An Example Problem (Roberts and Suhrbier, 1966) and in an article "Link Analysis for Route Location" (Roberts and Suhrbier, 1965). These works outline a very detailed system which generates data useful for engineering design, as well as cost comparisons of several alternatives. Unfortunately, the works begin with the proposed alternative corridors as "givens."

"The problem studied here is rather one of 'link design.' The decision to build this particular link, and for that matter each of the links making up I.R. 495, has already been made. The effect that building this link has on the operating characteristics of the entire system should have been considered earlier. The economic, social, aesthetic, and political impact of each major link and its feedback effect on traffic generation should be considered in the macrosystem problem. In the microproblem under examination here, traffic volumes, along with such subjective items as social and political impacts and indirect economic benefits have been assumed to be equal on each of the alternative alignments." (Roberts and Suhrbier, 1966, p. 3-4).

The process may still be of interest in its comparison of alternatives, even though the alternatives compared have been severely limited. The Roberts and Suhrbier approach is described below.

Digital Terrain Model Preparation

A topographic map showing the alternative alignments that must be evaluated is the basic data input. A study area or "band of interest" is then delineated on the map, with boundaries chosen to include all the alternatives, plus a bit of additional area to allow possible small changes in the outermost alignments. A horizontal coordinate system baseline is then set up within the band of interest (see Figure 4). This baseline forms the x-axis of the system, with y-coordinates being taken normal to the baseline. Then, using an automatic data digitizer, the x and y coordinates of selected points, as well as the elevation of each above sea level (z-coordinate) is recorded. The data can be output either onto punched cards or tape, or as in this study, as printed numbers on paper tape.

Digital Terrain Model Location System: Alignment Design Phase

The horizontal geometry of the baseline and of each alternative route is defined in terms of the state plane coordinate system shown in Figure 4. Coordinates of line segment end points, points of intersections with curves,

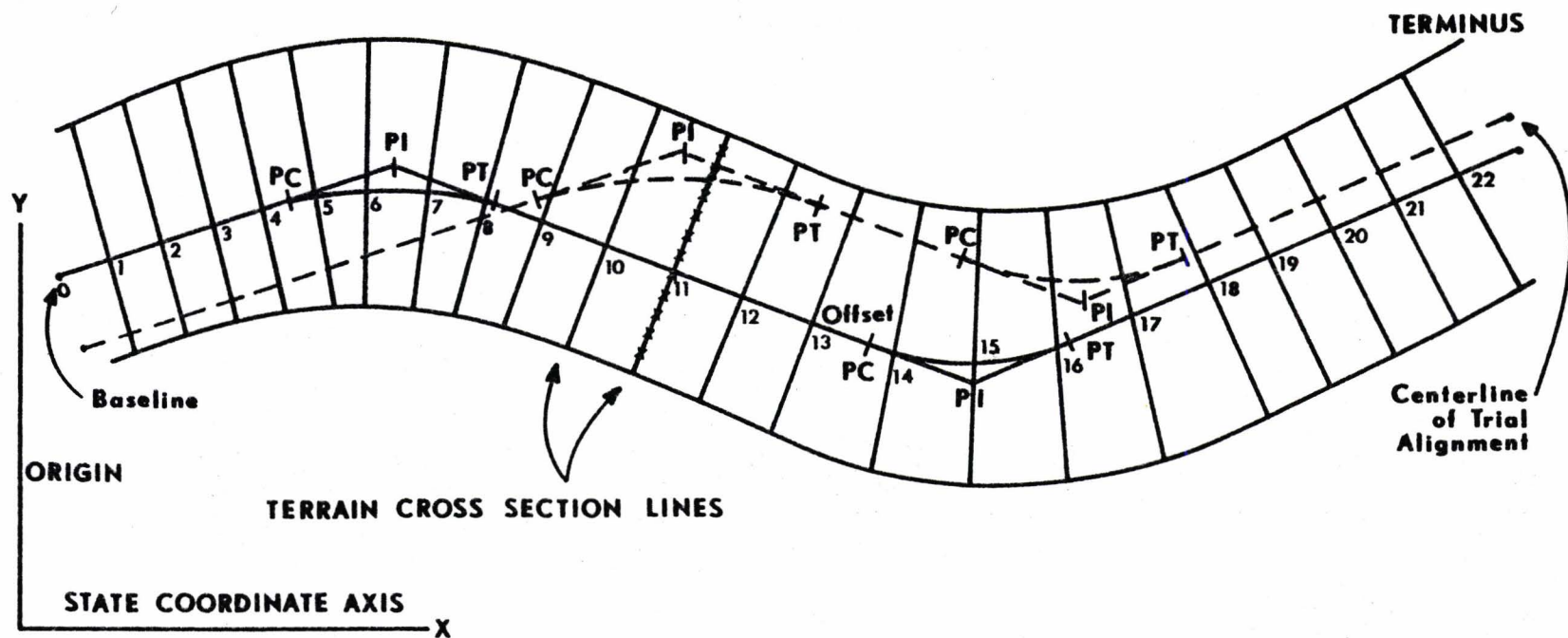


Figure 4
Digital Terrain Model Coordinate System

and a measure of each curve's degree of curvature are input. A computer program then generates additional points or stations on the baseline, relates the alternative route centerlines to the baseline, and calculates and plots the ground elevations for each centerline and two lines parallel to it on each side.

Roadway Design Phase

Using professional judgment and the elevation plots produced above, designers select trial vertical alignments for each alternative route. With the addition of a simplified design template for the desired road cross-section, and cut-and-fill multiplication factors, the computer program automatically calculates "the vertical geometry and grades, finished template shape for each road section, slope intercepts, area, volumes, slope limit plot, and mass haul diagram" for each alternative.

With these calculations complete, the original seven alternative routes were reviewed to determine those which were superior and deserving of more study. The authors describe the selection process as follows:

"First, if two or more alternatives had a common link, it was determined which one of them was the best over just this one link. This was done for each link within the network. Second, by means of a simple, least path algorithm, the best path through the network was determined. Third, the network was searched for possible additional combinations of links which would form an alignment sufficiently close to the best path to merit additional investigation."
(Roberts and Suhrbier, 1966, p. 33 and 34).

Digital Terrain Model Design System

This is similar to the Location System just described, but it uses more detailed terrain and design data. As a result, this phase is more accurate than the last, and also five times slower. Output from the Design System includes all the types of information produced by the Location System, plus "as-built" terrain cross-sections, a rock volume calculation procedure, and earthwork calculations for interchange

areas. These values are used in the cost comparisons made between the alternatives.

Economic Analysis

For each of the three remaining alternatives, the Total Annual Cost (TAC) was calculated using the following formula:

$$\text{TAC} = \text{Annual Capital Cost} + \text{Annual User Costs} + \text{Annual Maintenance Cost}$$

where: Annual Capital Cost considers cost of: earthwork, structures, pavement, drainage, interchanges, relocation, and land, as distributed over time by the interest rate and the facility service life.

Annual User Costs consider: present traffic volume, average projected traffic increases, the vehicle classes using the road, the costs of fuel, oil, tires, maintenance and depreciation for each vehicle class, the travel time for each class, its value per hour, and the cost of time unreliability.

Annual Maintenance Cost considers: the length of the road in miles, and the maintenance cost per mile.

The results from this study range from a TAC of \$3,467,000 for alternative 2, to \$3,923,000 for alternative 1, a difference of only two percent. The probable error in the calculations is believed to be larger than this variation. Even after disaggregation of the results by categories of costs, the alternatives were still very close. Sensitivity analysis was performed on the alternatives, allowing successive critical but uncertain factors to vary, while holding all others constant. The results appeared the same as before, with alternative 2 still preferable.

In commenting on the final decision, the authors said: "If least cost is to be used as the criterion for selection, line 2 will be the choice. Differences among the three final alternatives in terms of number of people and businesses disrupted or in social, political, and aesthetic impact upon the community were not felt to be sufficient enough to change the decision" (Roberts and Suhrbier, 1966, p. 82).

In contrast to Roberts and Suhrbier, Ian McHarg has taken a much broader view of route selection. In his articles "Where Should Highways Go?" (1967) and "A Comprehensive Highway Route Selection Method" (1968) and his book Design with Nature (1969) his stated purpose has been to "develop a method to reveal an alignment more responsive to social values and the natural environment and its resources" (1967, p. 180) than the standard Bureau of Public Roads criteria. The BPR criteria are not rejected, but McHarg aims "to incorporate social, resource, and aesthetic values in addition to the normal criteria of physiography, traffic, and engineering considerations" (1968, p. 2) (Emphasis supplied).

The method was developed as a result of citizen protest over the proposed routing of Interstate Highway 95 west of Princeton, New Jersey, and McHarg was retained by the citizens to develop a more responsive location for the road. This case is documented in the two articles cited above. Later the technique was applied to the location of a parkway on Staten Island, the New York Borough of Richmond, and described in Design with Nature (McHarg, 1969).

In the New Jersey study, twelve factors were deemed most important in the highway location decision. They included the physical determinants of topographic slopes, physiographic obstructions, and susceptibility to erosion, as well as social factors such as land values, residential housing value, recreational value, water value, historical value, wildlife

value, scenic value, agricultural value, and urbanization. In the later Staten Island study, agricultural value and urbanization were not considered, but other factors were added: tidal inundation areas, forest values, institutional values, surface drainage, soil drainage, bedrock foundation and soil foundation. The factors that are considered respond to both the physical setting of the study area, and the values of those involved in making the decision, whether they be engineers or citizens.

The method of handling the important factors is very simple, and is shown in Figure 5. Each factor is mapped as a transparent overlay with three gray tones, darkest for the area least compatible with the highway, lightest for most suitable. Then all of the factor maps are overlaid upon one another on a light table, resulting in a composite map of many dark and lighter areas. The lightest areas on the map indicate the locations most suitable for the highway, the alignment of "minimum social cost."

Obviously there are problems with this methodology. The most serious appears to be the equal weighting of the various factors by the preparation of one map for each factor. People may and do place different importance on the many aspects of such a problem, but it is very difficult to incorporate the weights into this particular process. For a simple problem with few factors, it would be possible to overlay or photograph one factor several times to give it more importance in the decision, but there is a very finite limit to the resolution possible by these visual means. Because of this weighting problem, and that of only three values recorded on each factor map, the corridor that is delineated by this method is not necessarily that of the minimum social cost.

However, the technique also has some good aspects. The concept is simple and easily understood, the graphics that are prepared are useful

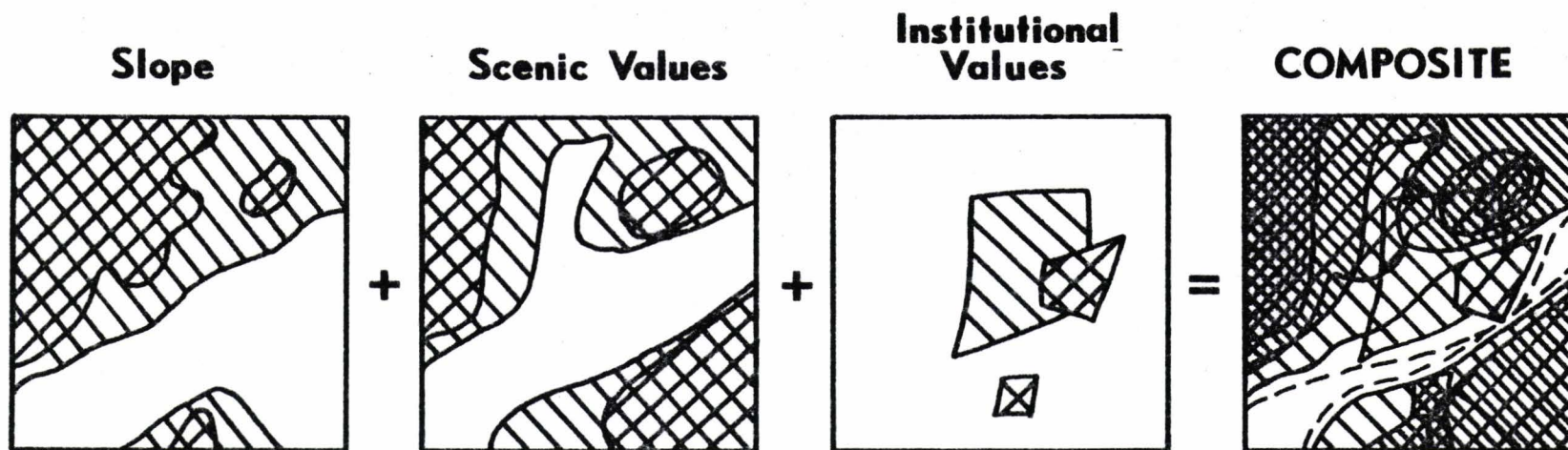


Figure 5
Factor Compositing by Overlay

for public hearings, and the method of preparation is relatively fast, low cost, and needs little advanced technology. Thus it may serve well in areas with limited resources available, as long as its limitations are understood. It does explicitly incorporate more factors into the decision process than had previously been included. And what is more, it is effective--in each case where it was applied by McHarg, his routing was adopted.

Another computer-based method for the location of highway corridors is the "GCARS" system. The basic procedures necessary for its implementation are described in Computer-Assisted Procedures to Generate and Evaluate Regional Highway Alternatives (Turner, 1968). "The GCARS System: A Computer-Assisted Method of Regional Route Location" (Turner and Miles, 1970) describes the complete system, and its test on an area in Indiana. And finally, "Computer-Aided Transportation Corridor Selection in the Guelph-Dundas Area of Ontario" (Turner and Hausmanis, 1973) discusses the application of the system to transportation planning in southern Canada.

The purpose for the system is to combine the computer's logic and data-handling capabilities with the judgmental capabilities of the engineer, in order to improve the planning of regional facilities such as highway corridor locations. This is necessary because of the inability of traditional procedures to explicitly incorporate aesthetics and environmental values into the decision process.

The first step in applying the system to a location problem is the choice of "route-independent" factors thought to be important to the final decision. These factors may vary widely, depending on the physical environment, values of participants, legal requirements, and many other conditions. The two applications of this system have differed considerably in the factors each considered, as shown in Table 3. Some of the above

Table 3

Route-Independent Factors Considered in GCARS Studies

1970 Study (Indiana)	1973 Study (Ontario)
Earthwork Cost	Earthwork Cost
Foundation Costs	Foundation Costs
ROW Acquisition Cost	ROW Acquisition Costs
Existing Road Network	Recreation Potential
Service Benefits	Wildlife Potential
Zone populations	Deer
Zone densities	Waterfowl
Zone trip ends	Upland birds

factors were mapped directly, digitized and weighted by professional judgment to reflect development or social costs. Other factor maps had to be derived from other data. For example, the application of numerical trend analysis or "smoothing" techniques to topographic elevation data was used to generate a surface geometrically satisfactory for highway building. The residuals of this procedure that is, the differences between the smoothed surface and the actual contours, indicate the amount of earth that would have to be cut or filled, and thus the relative earthwork costs of different areas. The result of these manipulations is a series of computerized "cost surfaces" or models, one for each factor. See Figure 6 for a graphic description of these surfaces, as well as an outline of the remainder of the process.

Then, using minimum path algorithms (Moore, 1959; Martin, 1963; Whiting and Miller, 1960) successive minimum paths are computer-generated for each of the factor's cost surfaces. The results of these are studied in order to understand the locational effects of each factor.

The factors are then combined into composites with several compositions and weighting emphases. For example, a composite can be generated that considers all factors equally (all weights = 1.0) or that counts scenic values twice as heavily as construction cost (scenic value weight = 2.0,

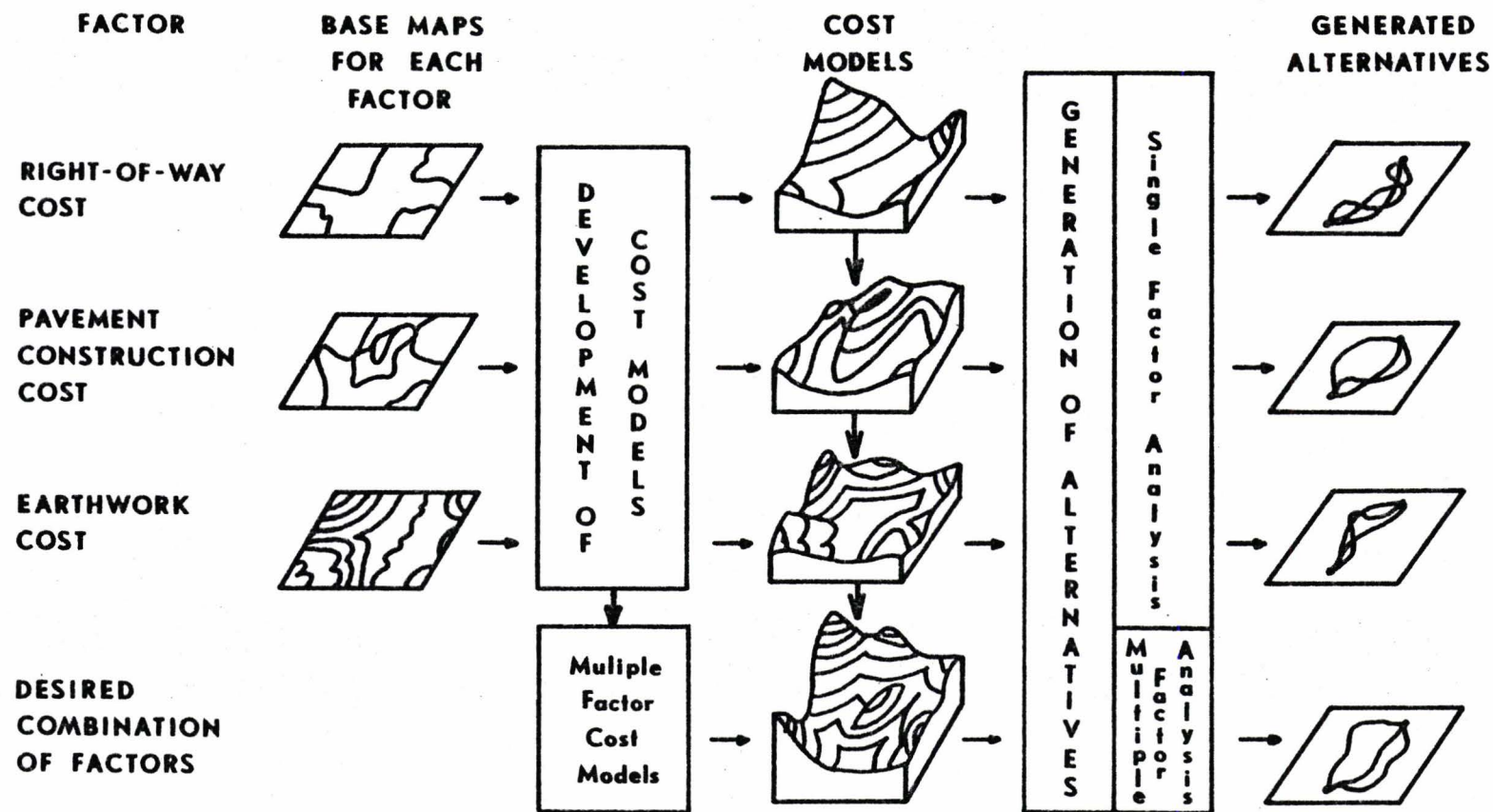


Figure 6
Basic Concept of GCARS

construction cost weight = 1.0). Because there are no absolute values that can be put on the importance of each factor in all cases, more than twenty different combinations of factors and weights were examined in each of the studies. The minimum path algorithm was applied to each of the resulting composites, and sensitivity analysis was used to assess the effect of weight changes on routing.

With those data, plus tabulations of alternative corridor lengths and relative suitabilities for highway purposes, the final selection was made. The 1970 study gave no details of the decision process, except that the composite used "is believed to represent a reasonable weighting of the factors." In the 1973 work, however, several composites generated the same "best" corridor. Thus, because of its relative insensitivity to a range of values, it was selected.

The approach described in "Desirability Rating and Route Selection" (Riedesel and Cook, 1970) is basically that of developing a framework which insures the incorporation of aesthetic, sociological and neighborhood economic values into the urban highway decision process. Measures for each of these values are developed, and then compared for several route alternatives, along with other traditional factors such as costs and benefit-cost ratios.

The initial step consists of developing "ratings" for the effects of each route alternative on the values noted above. Some subcategories considered important in evaluating the effects are tabulated in Table 4.

These subcategories (and some further subdivisions in the sociological area) are used to "rate" each unique section of each highway alternative on a scale of one to ten. The exact details of the rating process are not described in this article (see Riedesel, et al., 1968), but apparently professional judgment and some limited public input are used to quantify

Table 4

Variables Affecting Each Major Rating

APPEARANCE RATING	SOCIOLOGICAL RATING	NEIGHBORHOOD ECONOMICS
<u>Local/Sectional Eff.</u>	<u>Individual Effects</u>	<u>Property Values</u>
Scale relationship	Interactions	Residential
Noise factor	Effects on those with	Business
Barrier factor	low rates of adjustment	
Changes in area	Settlements	
<u>Metropolitan Effects</u>	<u>Local/Community Effects</u>	<u>Relocation</u>
City planning	Changes in members	Residential
Continuity & fit	Community attributes	Commercial
Respect for sacred areas		Churches, clubs, recreation and community services
Driver's exper.		
	<u>Metropolitan Effects</u>	<u>Service</u>
	Relationships between social areas	Employment centers
	One social area	Shopping centers
	Social attributes of metro area	Churches, clubs, etc.
	<u>Regional Effects</u>	<u>Miscellaneous</u>
	Wholesale trade area	Business site development
	Regional dominance	Opening new markets
	Communication and transportation	

the various effects. The authors state "the relative importance of specific effects in each case just be decided by interested, knowledgeable people in and out of highway departments" (Riedesel and Cook, 1970, p. 22).

With the effects of the highway on each subcategory determined, weights are devised to reflect the relative importance of each subcategory to the overall factor. Moreover, this is done for three separate time periods (0-5 years, 6-25 years, and 26-50 years) in order to deal with possible changes in relative importance over time. The weights for each subcategory and time period are then multiplied by the rating, and the results are summed for the whole factor. In order to determine the relative score for the particular alternative, the total is compared to

Table 5

Neighborhood Economic Considerations

(1) Considerations	(2) 0-5 Yr. Period			(3) 6-25 Yr. Period			(4) 25-50 Yr. Period			(5) Combined 50-year Weighted Rating
	Desirability Rating 1-10	Weight Factor	Weighted Rating	Desirability Rating 1-10	Weight Factor	Weighted Rating	Desirability Rating 1-10	Weight Factor	Weighted Rating	
E- 1 Residential Property Values	6	6.0	36.0	7	3.84	26.9	8	1.12	9.0	71.9
E- 2 Residential Relocation	4	4.2	16.8	5	.96	4.8	5	.08	0.4	22.0
E- 3 Business Property Values	7	9.6	67.2	8	5.44	43.5	8	1.52	12.2	122.9
E- 4 Business Site Development	7	10.8	75.6	8	6.08	48.7	9	1.60	14.4	138.7
E- 5 Commercial Relocation	5	6.6	33.0	5	2.24	11.2	5	.08	0.4	44.6
E- 6 Opening New Markets	5	7.8	39.0	5	4.80	24.0	5	1.28	6.4	69.4
E- 7 Service to Employment Centers	6	3.0	18.0	7	2.24	15.7	8	.64	5.1	38.8
E- 8 Service to Shopping Centers	6	3.0	18.0	7	1.92	13.4	8	.64	5.1	36.5
E- 9 Service to Churches, Clubs, Recreation and Community Services	7	4.2	29.4	8	2.88	23.0	8	.96	7.7	60.1
E-10 Relocation of Churches, Clubs, Recreation and Community Services	5	4.8	24.0	5	1.60	8.0	5	.08	0.4	32.4
Total Section Rating										637.3
Relative Section Rating 637.3/10										64

the one that would be generated if each subcategory had been rated ten. See the example in Table 5. Here the Total Section Rating of 637.5 is divided by the total possible points of 1000 divided by an arbitrary 100. The result is 64, which indicates this particular alternative makes 64 percent of the maximum score.

Next, the total factor rating for each alternative is calculated and recorded, as in Table 6.

Table 6

Factor Rating Calculatings
Rating Calculation Form, Route _____.

Section	Length of Section as % of Route Length	Relative Section Factor Rating	Length Times Rating
1	20%	40	8
2	50%	60	30
3	30%	80	24
Total Route Factor Rating:			62

Finally, the desirability ratings are arrayed with the other important considerations in order for the decision maker to evaluate the relative merits of the route alternatives. The format and factors which the authors considered relevant for this purpose are tabulated in Table 7.

The method which the decision-maker uses in selecting a route and explaining the choice is, of course, dependent on his/her values and perceptions of those of the constituency. However, the authors suggest two additional statistics that may be illuminating. These are the "desirability-cost" ratio and the "feasibility" ratio. The first is the summing of the ratings for appearance, sociological considerations, and neighborhood economics, and then a division by the annual cost in thousands

Table 7

Comparison of Route Alternatives

ROUTE COMPARISON FORM R

Considerations	Alternate Routes		
	A	B	Basic Condition
Fixed Value Considerations:			
R- 1 Funds Available			
R- 2 Completion Date			
R- 3 Legality			
Monetary Considerations:			
R- 4 Construction Cost			
R- 5 Annual Maintenance Cost			
R- 6 Annual Vehicle Operating Cost			
R- 7 Travel Time Cost			
R- 8 Accident Costs			
R- 9 Vehicle Mile Cost			
R-10 Benefit-Cost ratio			
Desirability Considerations:			
R-11 Appearance Rating			
R-12 Sociological Rating			
R-13 Neighborhood Economic Rating			
R-14 Institutions or Prohibitions			

of dollars. This ratio will show the necessary trade-offs between costs and social benefits. The "feasibility ratio" is the arithmetic sum of the desirability-cost ratio and the benefit-cost ratio (weighted to reflect relative importance).

There appear to be some substantial limitations involved in the system as outlined. For one thing, the procedure cannot be used to generate corridor alternatives. Many of the ratings depend on very specific route and design characteristics of the proposed highway, and thus, only very detailed proposals can be rated. Also, it may be difficult to predict many of the impacts of a facility yet to be built, especially for laymen, and over a fifty year time span. Finally, the choice of weights are subject to honest differences of opinion and value, but since the system does not appear to be computerized as yet, analysis of the sensitivity of results to different weighting schemes may be difficult and time-consuming to obtain.

Transmission Corridor Selection

As noted earlier in this paper, utility companies and others faced with the responsibility of locating electrical power transmission lines have also been involved in developing new methods for corridor selection. Much of the impetus for new approaches has been due to the increasing environmental awareness of the citizenry, but the single most effective factor has been the National Environmental Policy Act of 1969 (NEPA, 42 U.S.C. Sec. 4321 et seq., 83 Stat. 852, Pub. L. 91-190). This law requires that "...all agencies of the Federal Government shall....include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on the environmental impact of the proposed action..." (42 USC 4332). This means that government regulatory agencies such as the Federal Power Commission must file impact statements on power corridors which they approve, as must the U.S. Forest Service and the Bureau of Land Management, in cases where the corridors pass through the land which they control.

In order to expedite the approval process, the companies therefore have been preparing environmental analyses of their own, similar in format to the formal statements which the government agencies must file. These are prepared either in-house, or by consultants working with the utility company. Most of the reports discussed below are of the latter type.

One approach that should be familiar to the reader by now is used in EDAP: Environmental Decision Alignment Process (Neimann and Miller, 1973). This report is very similar to Miller and Neimann's earlier highway study (1972) with some detail changes and refinements. EDAP deals with the location and selection of transmission line corridors with the minimum environmental impact, in a 2000 square mile study area north of Madison, Wisconsin. As was done in the 1972 highway study, the approach is hierarchical: from the basic variables, to an aggregation into "components," combining the components into "determinants," and then generating several composite suitability maps, each incorporating different values and weights (see Figure 7).

However, there have been detail changes and refinements in the method. One change may have been a function of the smaller size of the study area, 2000 square miles versus 3500 square miles in the highway study. Cell sizes become 1/4 square kilometers ($1/2 \times 1/2$ kilometer) instead of the previous one square kilometer. As a result, the EDAP study contained 20,000 cells, over twice as many as the 1972 report.

The weighting process was changed and simplified. Instead of complex normalization calculations needed to standardize and make elements at the same hierarchical level have equivalent impact, a much easier process was devised. In the EDAP procedure, for any group of elements at one level, the sum of the weights is 100. See Figure 7 below. When this weighting technique was applied by the authors to the weighting

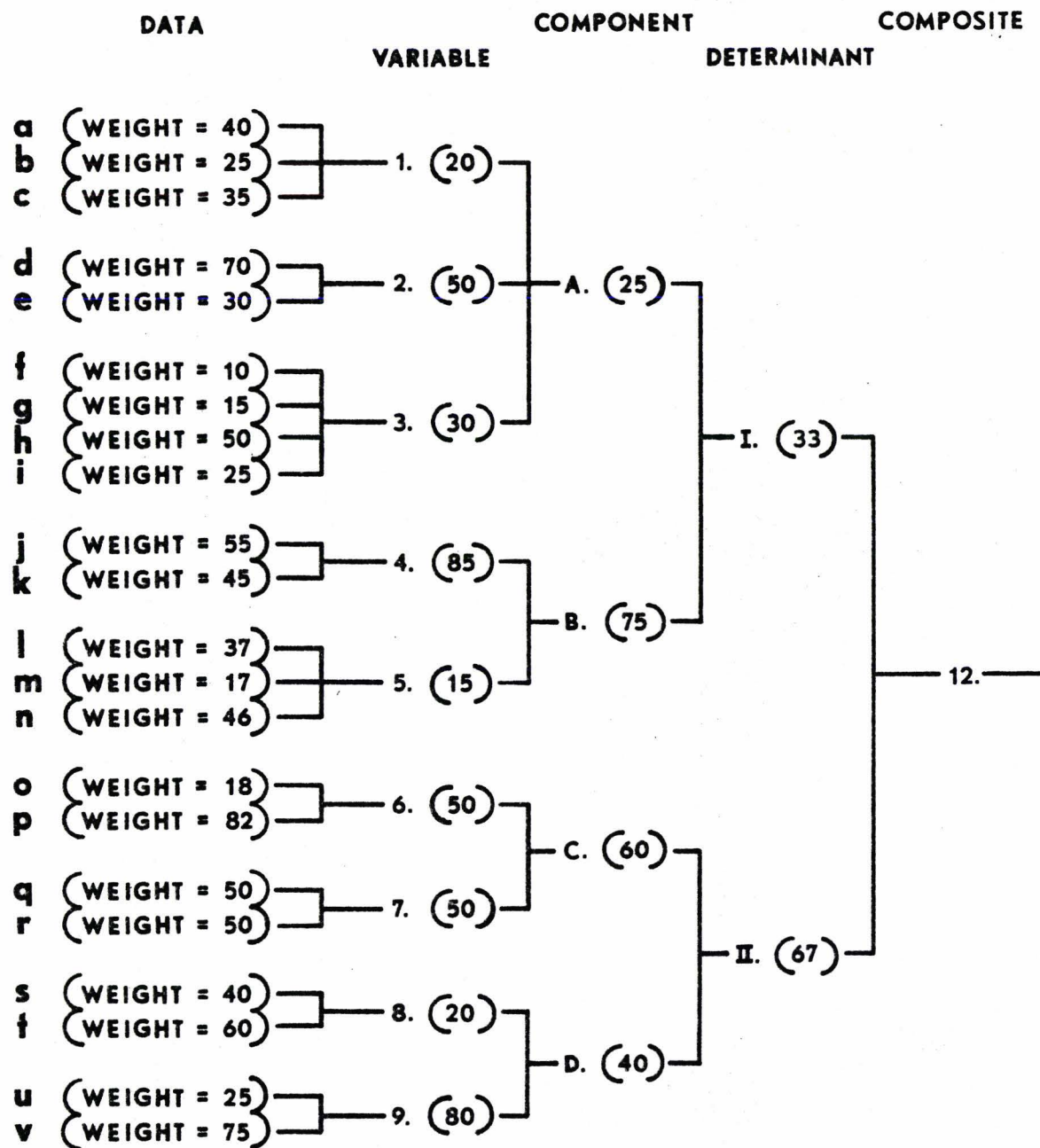


Figure 7

EDAP Weighting Process

calculations shown earlier in the section devoted to the 1972 Miller and Niemann study, the numerical results were different, of course, but the composite map generated in the example was the same. While this does not prove the equivalence of the two techniques, it may be an indication of similarity. Presumably any advantage in the rigor of the more complex normalization procedure is outweighed by the increase in conceptual and mathematical simplicity.

EDAP was also more computerized. Whereas many of the procedures before were performed manually, virtually all repetitive tasks in EDAP were handled by machine. These included optical scanning of data forms, data editing, generation of the optimal path ("The path of least resistance") through any suitability map, sensitivity analysis and impact analysis. These latter procedures grew out of the recommendations noted at the end of the highway study. They give the decision-maker another way of comparing alternatives, in addition to visual comparison.

In sensitivity analysis, the numerical values assigned to each cell location by the weighting process are added and averaged for each determinant, and each composite value map. This study used seven "determinants" and weighted them in different ways to reflect the important values of the area. Four interest groups' values were considered: the Naturalist's Viewpoint, the Farmer's Viewpoint, the Politician's Viewpoint, and the Tourist's Viewpoint. Each consisted of a different combination and weighting scheme for the seven determinants. For example, the Naturalist's Viewpoint gives equal (25%) weight to the determinants "minimization of disruption to agricultural land use," "to recreational land use," and "to natural systems," and "maximization of potential for functional right-of-way sharing," while giving no weight to the other three determinants--"maximization of compatibility

with urbanized land use," "with potential visual exposure," and minimization of financial investment." The other viewpoints weighted the determinants in different ways to express their interests. A fifth weighting scheme gives equal weight to each determinant. Fifteen other alternatives are generated by giving each of the basic viewpoints a dominant role in combination with a lesser role for the previously zero-weighted determinants, and by counting costs and/or right-of-way sharing more or less heavily. Each of these twenty policy alternatives weights the cell values in the determinant maps, to generate twenty composite maps each reflecting a particular value scheme. Ten alternative optimal alignments then are traced through the twenty alternative policy maps and the seven individual determinants, and the average cell value for each alignment in each composite map is calculated. The figures are then compared in the format shown in Table 8.

Table 8

Sensitivity Index--Comparison of Five Alternative Routes with the Composite Map of Farmers' Values (or other policy alternative)

<u>Route Analyzed</u>	(1)	Index
	<u>Mean Cell Value</u>	<u>(2) Minus (1)</u>
Alt. route optimal for Tourist Values	26.02	-3.30
Alt. route optimal for Politician's Values	23.92	-1.20
Alt. route optimal for Naturalist's Values	20.93	1.79
Alt. route optimal for Farmer's Values	17.84	4.88
Alt. route optimal for Equally-Weighted Values	<u>24.88</u>	<u>-2.16</u>
(2) Mean Cell Value for all Routes		
	22.77	

The index calculated in the last column indicates greater or lesser "responsiveness" by the various alternative alignments to the values of the farmer. The route optimal for the farmer's values, of course, has the highest responsiveness (4.88) to the composite of farmer's values, but it can be seen that the "naturalist's route" is also responsive, although to a

lesser degree. The other alternatives are progressively less responsive, with indices from -1.20 to -3.30. The decision may be able to use tabulations of this kind to select a route acceptable to competing interest groups.

The impact analysis program in EDAP tabulates the variables located in the cells of alternative alignments, calculates the total area of each variable that is contained within the corridor, compares that with the total area of each variable contained in the entire EDAP study area, and computes the percentage of that variable that is impacted. A sample output is shown in Table 9 below.

Table 9

Potential Impact of Alternative Route 14

<u>Variable</u>	<u>Total Acres in Study Area</u>	<u>Acres Impacted</u>	<u>Percent of Total</u>
Urban Land	5398	174	3.20
Agricultural--Row Crops	129766	119	0.09
Historic Site	323	0	0.00
Zoned Flood Plain	36044	125	0.30
3% to 6% slope	141114	795	0.50
Oak-Hickory Community--Closed	29092	272	0.90
etc.	---	---	---

By the use of this table, the decision maker can determine if large fractions of critical resources are impacted by the various corridors, and thus may eliminate certain alternatives from consideration.

Despite the use of many mathematical tools in this process, the final decision was made by human judgment weighing the various outputs of the system. Once the decision was made, the location of the final right-of-way within the selected corridor was determined by standard location constraints including legal, engineering, aesthetic, and ecological considerations.

The EDAP report is unusual in its broad exploration of alternative alignments. In it, virtually no possible alternative is foreclosed before detailed analysis and testing. The whole study area is investigated for optimal routings. A more typical approach is illustrated in two reports produced by a consultant for Tucson Gas and Electric Company, Applicant's Environmental Analysis, 345 KV Transmission Line, Tucson, Arizona to San Juan Powerplant, New Mexico (Westinghouse Electric Corp., 1971) and Applicant's Environmental Analysis, 345 KV Transmission Line, Westwing Substation to Vail Substation, (Westinghouse Electric Corp., 1972).

The first report, hereafter called Tucson-San Juan (Westinghouse, 1971) deals with the selection of a power transmission corridor from Tucson to northwestern New Mexico, a distance of 400 miles. Four initial route alternatives were selected using the criteria of directness, presence of access roads, and avoidance of the most mountainous areas. All four were rejected by major groups for political (Indian militancy), economic (interference with logging), aesthetic (interference with recreation), and ecologic reasons. One alignment was then modified and submitted as the proposed route. The remainder of the report is a discussion of the impacts of that route, and description of procedures that will be taken to minimize that impact. Within one to five miles of the centerline of the corridor as proposed, detailed studies were made of physical, ecologic, demographic, historical, aesthetic, and land use conditions. Criteria for right-of-way selection within the corridor included minimum environmental disruption with minimum land use conflict, use of existing rights-of-way, avoidance of historic sites, parks, recreation areas, wildlife refuges, steep slopes, prime timber areas, main highways, ecologically sensitive areas, and scenic areas, where possible. If avoidance was not possible, impact reduction was attempted, by means of extra construction care, visual

design, and other techniques. The remainder of the Tucson-San Juan study deals with the study elements mandated by the National Environmental Policy Act of 1969, presented in that format.

The second Tucson Gas and Electric report, short title Westwing-Vail (Westinghouse, 1972) proposes a power line corridor from the Westwing substation west of Phoenix to the Vail substation southeast of Tucson, a distance of over 180 miles. Nine initial alternatives were first delineated by avoiding all known archeological and historical sites, mining areas, existing populated areas, projected future areas of development, areas of ecological sensitivity, areas of high erosion potential, intensive agriculture, and high scenic value. As in the Tucson-San Juan study, numerous alternatives were rejected by affected groups and agencies, leaving only three routes, with seven distinct line segments.

The impact of each alternative upon each of the critical factors listed above was quantified, if possible, and displayed in tabular form for the three routes. However, units varied from factor to factor, making any sort of composite rating impossible. Fortunately, one route seemed superior in almost every aspect discussed, but this would be unlikely to occur in every analysis, especially where there are many more alternatives under consideration.

In comparison with the EDAP study, the Tucson Gas and Electric reports are not as detailed, especially in regards to the initial generation of alternative corridors. There appear to be several reasons for this. One may well be the relative scales of Arizona and Wisconsin. Arizona is characterized by large parcels of land held by Federal agencies, the Indian tribes, and the State of Arizona, where Wisconsin is relatively fragmented into smaller ownership patterns. Arizona also has large areas of land that have similar

physical characteristics, especially the alluvial plains, but Wisconsin is quite broken up by small lakes, rivers, hills, and valleys. The larger variable units in Arizona may act as major constraints on corridor location. For example, if the Papago Indians refuse permission to cross their land, several thousand square miles of territory and a number of alternative corridors may be scrapped. Therefore, these large areas may act as basic constraints on corridor location, with the corridors fitted into the relatively small regions between them.

Another possible factor shaping the technique used is the sparseness of the population in Arizona, outside of the large cities. Whereas Wisconsin has a relatively high degree of settlement in its rural areas, Arizona settlements are few, and far between and generally small. It may be that intensive land uses and population centers are so easy to avoid here that the utility management doesn't expect a large public hearing on the corridor, and thus doesn't bother to explore every possible alternative, or to justify every decision. Contributing to the attractiveness of a limited study are the double constraints of money and time. Neither has been in over-supply at TG&E the last few years.

It would seem that a McHarg-type approach with three-tone overlays would be ideal for the initial, broad-scale study to locate initial alternative corridors. However, as long as the Federal agencies continue to approve the present process, there is no incentive to change it.

The report by Battelle Pacific Northwest Laboratories has a format different from the other transmission line studies included in this paper. Entitled Measuring the Social Attitudes and Aesthetic and Economic Considerations Which Influence Transmission Line Routing (Hendrickson, Bahl, Gray and Maynard, 1974), it is not a location study for a particular corridor, but rather an examination of several general problems in location studies.

In the introductory section of the report, the authors discuss the ten steps making up the planning framework for recent transmission corridor studies. These are:

1. Determine the geographic boundaries of the study area.
2. Select mapping and data-handling techniques.
3. Enumerate and map natural and cultural baseline data.
4. Formulate desirable location strategies and map areas of environmental constraints to these strategies by combining baseline data.
5. Rate the relative importance of each constraint in order of sensitivity to modification and combine constraint maps into a composite suitability map.
6. Identify alternative transmission routes following paths of highest suitability (least overall constraint).
7. Field check alternate routes and select those appropriate for further study.
8. Make final route decisions and recommendations.
9. Prepare environmental impact statement and present information to appropriate agencies and the public (Hendrickson et al., pp. 8-9).

Items 3 through 6 are steps which have recently been added to the process in systematic ways. Despite the additions, the authors believe there are a number of "gaps and shortcomings" remaining. These problem areas are:

1) Planning process communication; 2) Minimization of long-range impacts; 3) Public participation; and 4) Impact quantification. In regards to communication, the authors stress the need for clarity of presentation, especially when computer manipulations are involved. And they believe that long-range impacts can be minimized if efforts are made to coordinate the many levels of long-range plans prepared for an area. However, their main emphases in this report are discussions on the incorporation of public

participation into the process, and techniques to use in the quantification of aesthetic and economic variables.

Public participation in projects of this kind has both practical and philosophic justification. Practically, the consideration of various viewpoints in decision-making may prevent costly public intervention when the project is well advanced. And democratic theory maintains that those who are affected by a particular action should have a voice in the decision. Because of the complexity of the decisions to be made, certain methods of participation are seen as more effective than others. The Battelle study proposes early input at an intermediate level of participation (consultation) by a broad spectrum of groups, including those with special interests, occupations, and locations.

Once the participants have been selected, the next problem concerns the choice of criteria by which corridor alternatives will be generated and judged. Most corridor studies have relied on criteria drawn up by the study staff, on the basis of professional judgment. In the case of the Battelle report, the staff proposed seven categories of impacts by transmission lines, including aesthetics, water, air, economic, cultural/recreational, health/safety, and animal/plant impacts. (Land use was originally included, but was found to be redundant.) There are, however, alternatives to staff-generated criteria. One is the administration of a survey to the groups previously determined, in which the people are asked what criteria are important to them (Niemann and Murray, undated). Another is the use of "multidimensional scaling" (MDS) to extract personal criteria from judgments made between two stimuli (Nunnally, 1967). For example, pairs of slides of various transmission lines could be shown to respondents, accompanied by a general discussion of impacts. The respondents are then asked to judge the degree of similarity between the two slides of each pair,

without being told the basis for the judgment. Each person uses his or her own criteria, which are discovered in the analysis of the data.

When the major criteria for corridor evaluation have been determined by one of the methods discussed above, the importance of each criterion to the overall decision must be determined. The easiest approach is to ask participants to simply assign numerical weights to each of the criteria. However, Battelle's review of the literature indicates that the internal complexity of this task is so great that there are serious uncertainties regarding the weighting's true reflection of the respondent's values. Another method of weighting is to have the respondents rate each proposal for its "acceptability" by each criterion, and then rate the proposal's "overall acceptability." By multiple regression analysis, correlation coefficients between individual criterion ratings and the proposal's overall acceptability can be determined, as well as the relationships between individual criteria. These relationships are then used to generate the regression weights for each term, each weight representing the "importance" of that criterion to the overall relationship. This method works best where criteria are clearly differentiated. When criteria overlap (either actually or in the minds of the respondents), analysis becomes progressively more difficult. This method deals with group data, but, another indirect approach analyzes individual responses, attempting to determine individual weights. In this latter method, called "policy-capturing," photographs of particular proposals are assigned weights by experts in regards to each of the criteria. Then each individual respondent is asked to give an overall acceptability rating for each of the photographs. By multiple regression, each individual's value scheme can be determined, then compared to those from other individuals to discover broad groupings of values.

In applications of these techniques to real problems, the Battelle

authors recommend the choice of existing lists of important criteria, unless enough time and resources are available for a multidimensional scaling experiment. For weighting procedures they suggest the use of both direct ranking of criteria and policy capture analysis. The ranking serves as a check upon the findings of the policy capture phase, while the latter allows the "calibration" and quantification of the rankings into an interval scale of criteria importance.

In the final process, experts "score" each alternative route for its degree of impact upon each criterion. This score is then multiplied by the societal weight that has been determined for the criterion. The weighted scores can then be compared for all alternatives, or summed and the totals compared. The authors suggest a root-mean-sum as the preferred method.

Despite the output of numbers, the decision maker cannot simply apply this method blindly, accepting the numbers without question. Several limitations of the process demand critical interpretation. For example, care must be taken that information presented to respondents is as accurate, unbiased, balanced, and neutral as possible. Otherwise, the values generated may be predetermined. Possible instability of values over time must be considered, as well as the hypothetical nature of the value judgments with which the respondents are faced. Would they react differently if faced with a transmission line in their back yard? And finally, how much weight should be given to the weights generated by public participation? Human judgment is still required in the final decision, although the quantitative techniques discussed above can help to make better informed choices.

A second major section of the Battelle report deals with a quantification method for visual aesthetic values. In the initial data preparation and preliminary analysis phase, four overlay maps are prepared to show:

- 1) Landscape classification (landforms and land cover patterns): Facility compatibility with the landscape (based on screening potential, continuity of vegetative and land use patterns, and compatibility in terms of scale, land use, and landform).
- 2) Scarce visual resources (at both micro- and macro-scales); fragile visual resources (edges, landmarks, overlooks, special districts).
- 3) Viewer sensitivity (both by residents of an area where a facility is to be located, and by those passing by the facility. The latter is a function of the traffic pattern interaction with the pattern of visual resources).
- 4) Mitigation potential (where visual impact could be reduced by construction techniques, screening, color, etc.). And areas of future impacts, where land use changes are proposed.

Once the data above have been assembled, they are to be integrated into a composite. (Presumably this is to be done by a McHarg-type overlay, but it may be an appropriate situation for computer mapping, weighting, and combination.) The composite should help to identify possible corridors, and to show areas of "potentially high visual impact." If several corridor alternatives pass through high impact zones, a series of photographs of these areas should be taken, to show their appearance both "before" and "after" the proposed facility is built.

In the visual quality evaluation phase, at least five evaluators are chosen, most from the "general public" but at least one having "a professional design background." The evaluators view the "before" and "after" pictures, and score each as to its "vividness, intactness, and unity." The visual quality (VQ) rating of each evaluator for each view is then calculated as $VQ = 1/3 (\bar{V} - \bar{I} - U)$ where:

$$\bar{V} = \frac{\sum (\text{Vividness of each picture element}) \times (\text{Importance of the element})}{\sum (\text{Importance of each picture element})}$$

$$\bar{I} = \frac{\sum (\text{Intactness of each picture element}) \times (\text{Importance of element})}{\sum (\text{Importance of each picture element})}$$

$$\text{and } U = \frac{(\text{Unity of the overall view} - \text{Unity of man-made and natural elements})}{2}$$

Finally, the ratio of change (R) in visual quality is calculated for each view pair (before and after) as $R = (VQ_a - VQ_b) / VQ_b$, and the visual impact of the change is a function of R and a population contact factor. The seventh root of people viewing the facility per year was used arbitrarily to reduce the size of the number, and the final relationship is:

$$VI = R \times \sqrt[7]{\text{Population contact per year.}}$$

With the visual impact index calculated for each proposed alternative, comparisons can be made in terms of the relative visual effects. The results can also be input into the larger decision process with elements such as cost, environmental disruption, and so forth.

The last portion of the Battelle study discusses the possible use of the change in nearby property values as a proxy measure of the social cost of transmission lines. Although perhaps of interest in location studies for urban, privately-owned areas, it does not seem to be directly applicable to the planning of roads in the lands administered by the U.S. Forest Service.

One transmission routing study, at least, has incorporated public participation into the process in a systematic way. Entitled Ontario Hydro 500 KV Transmission Line Right of Way Lennox-Oshawa Environmental Report (Hartman et al., Commonwealth Associates, Inc., 1974) the report describes the process of selecting a 100-mile powerline corridor in southern Ontario. The general approach of the study will be discussed, followed by details of the public participation component.

As in most studies, the first step was to define objectives--criteria considered important in the location of the transmission line corridor. Six objectives were initially chosen, and, after addition of one more objective, and the combination of two of the original items, the following six were used: 1) minimize damage to natural systems; 2) minimize conflict

with existing land uses and visual exposure; 3) minimize conflict with proposed land uses; 4) minimize conflict with culturally significant features; 5) maximize potential for right-of-way sharing; and 6) minimize conflict with capability analysis (an inventory showing lands of high capability).

A 1400 square mile study area was chosen, constrained by natural barriers (Lake Ontario and Rice Lake) and by the endpoints of the proposed transmission line. Since the data manipulation was to be done by computer, a basic data cell was delineated, 250 meters square, about 15.5 acres. The whole study area contained about 60,000 cells.

Selection of the variables that affected the various objectives chosen above were professional judgments based on the nature of the objectives themselves, and the availability of data. Ten variables were chosen: 1) topography; 2) surface hydrology; 3) existing land use; 4) existing roadways; 5) communications and utilities; 6) proposed land use; 7) unique features; 8) outdoor recreation capability; 9) average soil capability for agriculture; and 10) capability for waterfowl. These were further subdivided into 75 categories such as "16-30% slope," "cropland," etc. More than five months were spent gathering data and mapping it by computer.

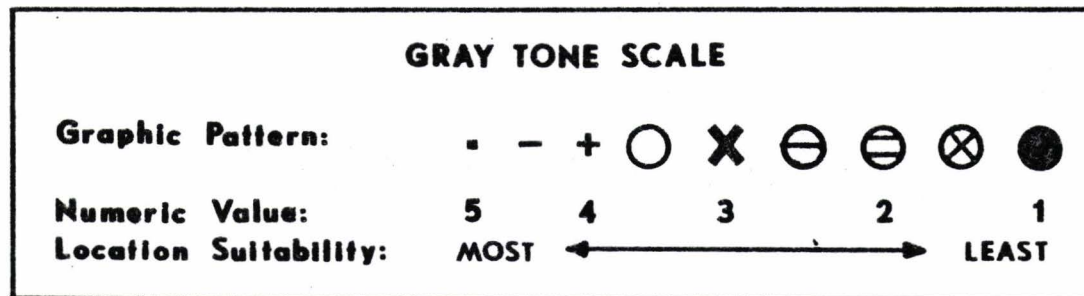
In the meantime, public attitudes were being studied, news of the proposed corridor was disseminated through the media, and public meetings on the proposal were scheduled in each township of the study area. At the first round of meetings the project was outlined and the need for the facilities explained. Next, the participants were divided into small groups to play a "transmission line routing game," in order to expose them to the many issues and trade-offs involved in the decision. Finally, those in attendance were asked to rate all of the objectives and all of the variables on their "importance." A five-step scale was used, ranging from "very important" (5)

through "unimportant" (1).

The original plan was that professional judgment and citizen input would be treated equally in the value determinations for objectives and variables. The staff had already made their ratings. However, when the citizen ratings for the variables were tabulated, they did not appear to correlate well with the data inventory. So instead of combining the two rating systems (professional and public), the professional weights were used for the variables, and those developed by the public were used for the objectives.

Once the weights had been determined, the next step was to apply them to the data. Each variable (topography, land use, etc.) was mapped for each township by computer. Then the professional weights were applied to the various data categories to show areas of more suitability and less suitability for transmission lines. For example, cells that had slopes of greater than 15% were assigned values of 1 (unsuitable), while those with slopes less than 15% were given values of 5 (very suitable). This weighting process was done for every variable. By averaging the values assigned to a particular cell for all the variables considered important for a specific objective, that cell's suitability for transmission lines vis-a-vis the specific objective is determined (see Figure 8).

Then the objectives themselves were combined into a composite suitability map, using the ratings generated at the public meetings to weight the objective maps' cell values. The values of each objective map are multiplied by the weight the objective is to be given in the overall decision. Then the weighted maps are added together to generate the final composite map of all objectives.



OBJECTIVE:

Minimize
Damage to
Natural
Systems

VARIABLES:

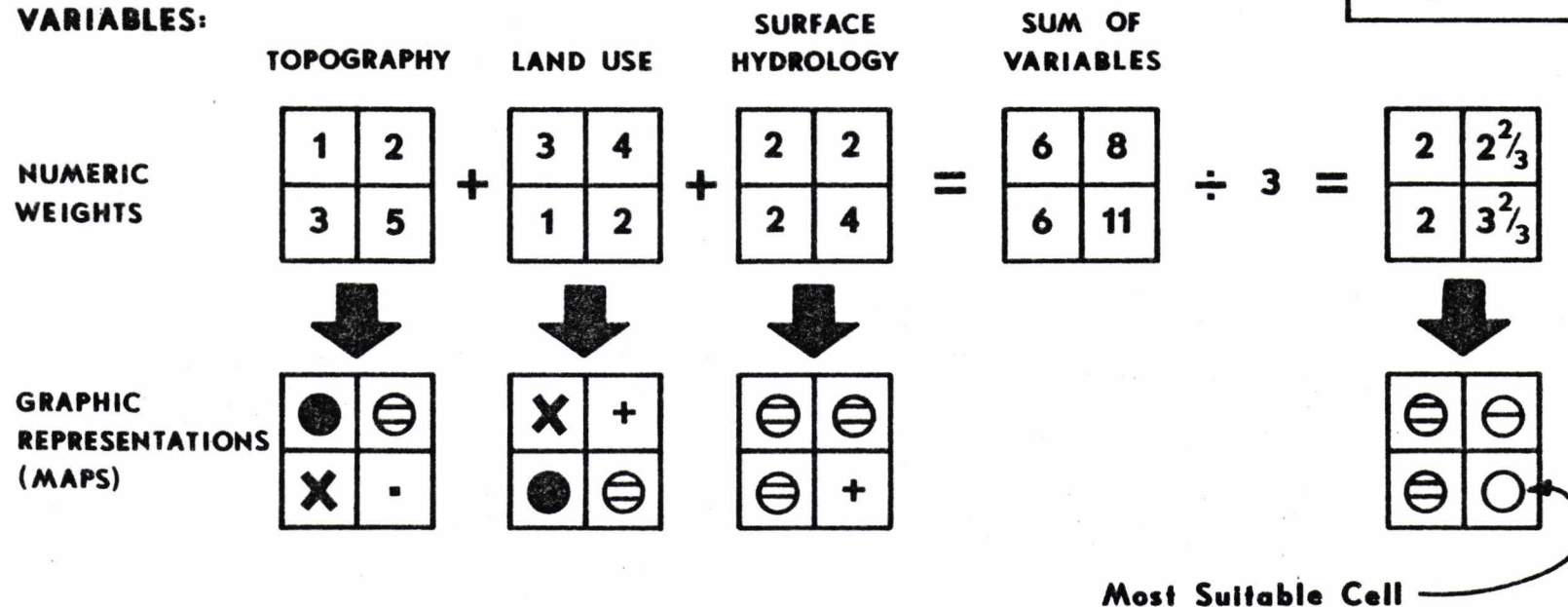


Figure 8
Compositing Objectives from Variables

The objective and the composite maps of all the townships were assembled into maps of the whole study area. Then several alternative corridors were drawn, by manually connecting areas of lighter tone (higher suitability). After studying specific impacts of each alternative, and the construction/acquisition costs of each over time, Ontario Hydro announced a second round of public meetings to present the alternatives.

Since the last meetings, the ratings of variables and objectives generated at each township meeting had been tabulated and publicized in each township. Additional background material was made available to citizens of each township so that they could familiarize themselves with the important issues. And a "preference ballot" had been sent out to each township to allow the citizens to "vote" for the alternative corridor which they preferred. The result of this campaign was a considerably larger turnout for the second series of meetings.

These meetings were devoted to project review, questions and answers, discussions of concerns of each township, and explanation of the "preference ballot." The final corridor selection was made by intuitive balancing of the local concerns with financial, regional, environmental, and technical considerations. Then a more detailed analysis was done of the chosen corridor, resulting in an environmental impact report, and the selection of the exact right-of-way.

Despite the large size of this report, and the amount of data that was needed to produce it, the methodology used does not seem that sophisticated when compared to either the Battelle study or to EDAP. Each of the categories within the variables are assumed to have equal weight, and the final decision process appears unaided by any mathematical analysis of the data collected, except for construction/acquisition costs. Yet the report is important in its explicit incorporation of local values, and the testing

CHAPTER III

OTHER USEFUL WORKS ON ASPECTS OF THE PROBLEM

Only a few of the several hundred works reviewed for this study dealt with corridor selection in a "comprehensive" way. These were discussed in the last two sections. However, many other publications deal with important individual elements of the problem. Some of these will be discussed in this section.

Networks

One useful way of looking at a road system in a National Forest (or anywhere) is to consider it as a network. A network is a group of points (nodes) connected by lines (links). A very lucid presentation of network types, measures, and characteristics and their relevance to transportation studies is given in Chapters Four and Five of Geography of Transportation (Taaffe and Gauthier, 1973). Basic studies of networks are concerned with the relationships between the number of links and the number of nodes. These generate indicators of the connectivity of the network. Changes in a network's connectivity over time may be studied, as may correlations between connectivity and other variables in several different networks.

Another concern is that of modal accessibility. How many links must be traversed in order to get to node 2 from node 1? And what is the total accessibility measure of all nodes in the network in relation to all other nodes in the network? With certain algorithms described by Taaffe and Gauthier, this can be calculated, so that several networks can be compared in terms of accessibility. As can be seen, this measure of accessibility is a function of the topological distance between nodes,

the number of links that must be traversed to get from one node to another. Other formulations are possible. Values may be assigned to the links of a network to represent other types of distance. For example, values given could be road mileage, travel time, construction cost, environmental costs, or many other variables. Such "valued graphs," as they are called, may be analyzed to determine routings minimizing travel time, maximizing accessibility, or other functions. Specific algorithms for computation are given in Pollack (1960), Prim (1957), Moore (1959), and other works listed in the bibliography.

An interesting work presenting applications of network and graph theory to analysis of transportation problems is "Optimal Transportation Networks: A Case Study of Highway Systems" by MacKinnon and Hodgson (1970). In this work, the authors compare the existing highway network of southern Ontario with networks derived from minimization and maximization functions. One of those used was that of the "minimum spanning tree." This is "the shortest possible network which joins all of the nodes so that one and only one path or set of links exists between any pair of nodes" (MacKinnon and Hodgson, p. 269). A rationale for the possible use of this algorithm in a network design might be the proportionality between construction cost and distance, and the desire to minimize the cost.

Another approach was the generation of a "shimbel network." This network aims at maximizing accessibility by minimizing the sum of all the internodal shortest path distances, subject to the constraints of connectivity and a maximum network length. One problem with this approach is computation. As the number of nodes is increased, the number of possible networks generated follows the function $2^{N(N-1)/2}$. The number of networks

that must be examined is compared with the number of nodes in Table 10.

Table 10

Number of Networks that Must be Examined
in a "Shimbel" Optimization

Number of Nodes:	3	4	5	6	7	8
Number of Networks:	8	64	1024	32768	2.1×10^6	2.7×10^8

Because of the massive numbers of possibilities for non-trivial situations, it would be extremely costly and time-consuming to work through a true optimization. Therefore, approximation (heuristic) algorithms are used to solve this problem.

A final network generation approach was that of a "gravity model." The goal in this case was to maximize the sum of the nodal populations times their accessibility, $\sum_{i=1}^N P_i A_i$, where accessibility $A_i = \sum_{j=1}^N P_j D_{ij}^{-b}$. Population of node i is given by P_i , the distance from node i to node j is D_{ij} , and $-b$ is the exponent that controls the "spatial friction" of distance. Although this model is simple (some say too simple) and easy to calculate, it has several drawbacks. It neglects any effects from external traffic coming into the network from the outside, it assumes each link has an infinite capacity, and that there are no costs of congestion.

In the comparison between the generated networks and that really existing in southern Ontario, all of the new networks had correlation coefficients of .61 to .635. Obviously, there is still a good deal of difference between the models and reality in southern Ontario, but this should not prevent use of these techniques on forest problems. Transportation systems in forests are much simpler than those in urbanized areas, and it is quite possible that one or more of these models may be applicable.

The problems of weighting objectives and choosing alternatives

In the forest road planning problem, several alternative plans will be generated, if only to satisfy the requirements of NEPA. They will be compared and judged against several criteria, most notably that of minimum environmental impact, but also items such as construction and maintenance costs, accessibility, and others. Since it is improbable that one alternative will be superior to the others for all the criteria or objectives, the problem of deciding the relative importance (the weights) of each criterion to the final decision must be faced. Donald Grant, in his article "The Problem of Weighting" (1974), discusses approaches that have been used to deal with the problem.

According to Grant, they fall into two basic categories. One group holds that differing criteria have to be aggregated systematically in order to successfully solve the design problem, while the other group claims that the criteria cannot be aggregated. Several subdivisions of each faction exist. These are shown in Table 11 below:

Table 11

Schools of Thought on Integration of Differing Criteria

Criteria must be aggregated

1. Judge the performance of each alternative against each criterion by using a uniform scale, then assign numeric weights of relative importance for each criterion.
2. Using a uniform scale that can be applied to all the criteria, combine the partial judgments without weighting. Scales that can be used include: a) monetary scale; b) a graphic scale; or c) a semantic differential.

Criteria cannot be aggregated

3. Find out which criterion is the most important, and decide on that basis alone; let the other criteria fall where they may.
4. "Consider all criteria carefully, then sit back and let the matter incubate, and an implicit, intuitively derived decision may emerge."
5. "Attempt to construct compelling patterns from the partial judgments, without deliberating weights
(Grant, p. 141).

Grant, along with Churchman and Rittel, considers approach 1 the best. Method 2.a is a strongly competing economic approach, but Grant criticizes it on the grounds that assigning monetary values to intangibles is uncertain, the utility of money is not uniform, changing with time and respondent, and the time-value of money is indeterminate. Approach 2.b was used by McHarg and implies equal weights of one for each criterion. Grant neglected to discuss the merits of 2.c, but for those who are interested, those using the technique include Osgood, Tannenbaum, Suci, Kasmar, and Wiggins.

The method shown in 3 is representative of the traditional, stereotype use of benefit-cost in public works decisions. Direct monetary costs and benefits are the only criterion--intangible benefits and costs are ignored. This is not acceptable in the complex problems of today. Method 4 is championed by J. Christopher Jones, and represents the technique of the traditional master designer. This approach has been used for the design of many beautiful works in the past, and will be in the future. Yet the vast knowledge and talent needed to intuitively integrate complex criteria limit its use to only a few people. Finally, Method 5 includes the techniques of Alexander and Manhein and of Ian McHarg. This procedure assigns implicit weights to the various criteria considered, and so claims an unwarranted neutrality. Grant argues for the inclusion of explicit weights, as a means of self-education, and as a means of choosing rationality over accident. Additional justification may be in terms of increased replicability, accountability, responsiveness, and knowledge of the design process.

Another excellent report deals with the problem of weighting as part of the problem of selecting the best alternative transportation plan.

07

Strategies for the Evaluation of Alternative Transportation Plans (Thomas and Schofer, 1970) first shows that the old benefit-cost techniques are no longer adequate and then proposes the use of the method of cost effectiveness. Three steps are necessary for the development of a scheme to rate the effectiveness of alternative plans: 1) the goals and objectives of the area must be determined; 2) the extent to which various goals and objectives are reached must be measured; and 3) the weights or values of the objectives must be derived. This last point calls for the development of indifference curves between the objectives to be considered, but the analyst cannot do it alone. The opinions of the citizens have to be taken into account.

Unfortunately, that is easier said than done. Some of the problems include 1) the values any one person holds are not necessarily consistent; 2) in the aggregation of the data, should the opinions of some people be given more weight than others, and should more intense feelings count more? and, 3) it is difficult for people to know how they feel about abstract plans.

Despite the problems, Thomas and Schofer believe that the cost-effectiveness approach is the only feasible approach. Some positive aspects of the method include possibilities of using the Delphi technique to elicit values from small groups with relatively homogeneous characteristics, and the use and analysis of attitude surveys to determine deep-seated values, rather than opinions on specific proposals.

Throughout the study, the authors concentrate on generating "good" transportation decisions rather than the optimal. They state that an optimal solution requires the following conditions:

1. "All feasible solutions must be known."
2. "All consequences must be known," and

3. "Optimality must be precisely defined" (Thomas and Schofer, p. 45).

For complex transportation planning problems, only a few of the many alternative plans are pursued and delineated in detail. Without the generation of all possible alternatives, the likelihood of the selection of the best possible alternative is small. Due to uncertainty about the future, the complexity of the interactions, and man's limited capacity for analysis, Requirement 2 appears to be unsatisfied. And in the usual situation of goal statement ambiguity and goal changes over time, it may not be possible to satisfy Requirement 3. It may be easier to approach these requirements in a situation like forest road planning, especially in regards to items 1 and 3, but the required knowledge of all consequences may prove to be a stumbling block.

The authors suggest some useful additions to the list of plan consequences to be considered. One is to disaggregate the effects of each plan to see how it affects different income groups, geographic areas, and so forth. And they suggest the study of "time streams of consequences of alternative plans" where there are priorities in the objectives, or where the alternatives may have consequences coming at significantly different times.

Resource Analysis

An excellent overview of different approaches to resource analysis for planning is given in A Comparative Study of Resource Analysis Methods (Steinitz, Murray, Sinton and Way, 1969). Sixteen different methods were applied to a study area southwest of Boston in an attempt to learn some of the strengths and weaknesses of each method.

The study area chosen was of a "regional" scale, about 520 square miles, or about 1300 square kilometers. The authors had participated in

other similar studies at varying scales, and chose a basic data cell size of one square kilometer for use in computer mapping. Data sources for the area were assembled, and procedures and programs written to extract and manipulate the data.

The next step was the acquisition and analysis of the materials available for each of the resource methods. The methods used were those of 1) Richard Allison and Roger Leighton, University of New Hampshire; 2) the Chester County (Pennsylvania) Planning Commission; 3) C. S. Christian, Australia; 4) John A. Dearing, University of Kentucky; 5) G. Angus Hills, Ontario Dept. of Lands and Forests, Canada; 6) Philip H. Lewis, University of Wisconsin; 7) R. Burton Litton, University of California/Berkeley; 8) Ian L. McHarg, University of Pennsylvania, and partner in Wallace, McHarg, Roberts and Todd; 9) State of California Parks and Recreation Dept., Paris Mode; 10) a systems analysis of outdoor recreation, RECSYS, developed by several agencies of the State of Michigan; 11 and 12) the Soil Conservation Service, U.S. Dept. of Agriculture; 13) Richard E. Toth, Harvard University; 14) U.S. Army Corps of Engineers; 15) Edward A. Williams, of Ecbo, Dean, Austin and Williams; and 16) Ervin Zube of the University of Massachusetts at Amherst.

Each method was intensively studied, and then applied to the study area. In some cases modifications were necessary to fit the methods to this situation different from their original applications. When this occurred, the new procedures used were chosen to be as consistent with the other procedures of the method as possible.

Once the various approaches had been used, the results and experience were analyzed to try to determine the strengths and weaknesses of each. It is not possible in this space to restate these findings for each method--readers are directed to the original report. However, some

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general comments on the methods may be in order.

One finding that the authors noted was that the supply side of the resource was studied by most of the methods, but half did not investigate the associated demand for the resource. One problem with attempting to do both is that resource supply data is often most appropriately collected on a natural resource base (watershed, etc.) while demand is a function of population, collected on a political basis. Another data problem was the frequent consideration of the study area as self-contained, with no supply or demand influences crossing the boundaries.

The authors recommend that resource analysts be more explicit in their handling of data and variables. For example, a number of techniques aggregated groups of variables into "key elements." This is fine, except that some variables appear in more than one element, implicitly weighting them. Steinitz et al., criticized the aggregation of nominal and ordinal data. They also felt that many of the methods were sub-optimally constrained by data availability, yet the authors did not discuss the implications of this for the validity of their reports.

Most of the works assume that if resources can be developed, they should be. Exceptions are the methods of Lewis, McHarg, and Zube. And the demand functions that are used appear to depend solely on the resource capability to support it. While this is part of the relationship, demand also is a function of the transportation system.

These criticisms should be kept in mind by any aspiring analyst, while browsing through this book trying to find a resource analysis method appropriate for his or her problem. Unfortunately, one of the most useful measures in assessing approaches, cost effectiveness, is never given in the original reports.

Environmental impact analysis

Since the goal proposed for this forest roads project is the selection of road locations with minimum environmental impact, a review of several impact assessment procedures may be in order. An early model was A Procedure for Evaluating Environmental Impact (Leopold, Clarke, Hanshaw and Balsley, 1971) published as a circular by the U.S. Geologic Survey. In this report, the authors skimmed over the preliminary stages, many of which should already have been evaluated as part of standard project procedures. The first five steps are:

- 1) State the project objectives;
- 2) Discuss the alternative technologies to reach the objectives;
- 3) Propose alternatives;
- 4) Inventory the environment of the proposed project; and
- 5) Analyze the benefits and costs of each alternative.

Then the authors get into the main focus of this report:

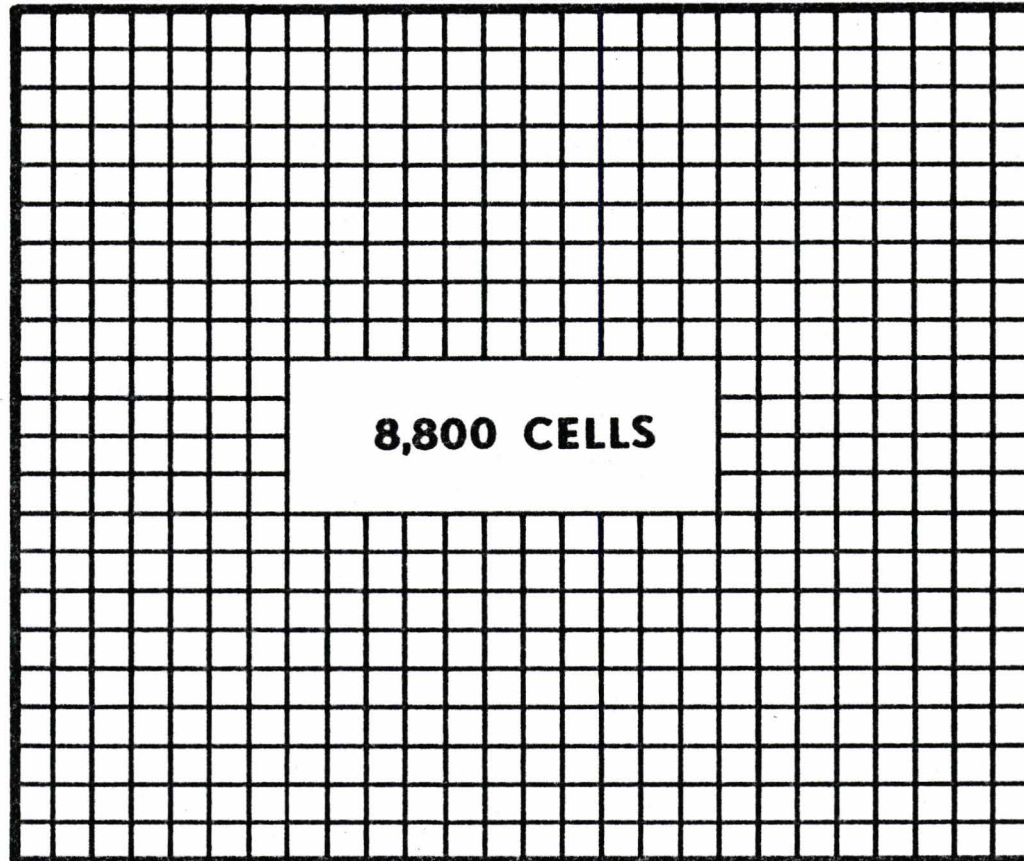
- 6) Identify the environmental impact of the proposed action and the main alternatives. Two steps to doing this are:
 - a) determine the magnitude of the impact (from facts);
 - b) determine the importance of the impact (from values).

"Magnitude," as used here, indicates the degree of impact that the project may have on specific sectors of the environment; "importance" deals with the significance of the impact to the environmental element affected.

Because of the complex interactions that may be the result of changes in the environment, the authors suggest the use of a matrix to keep track of the environmental effects, and to possibly identify alternatives to proposals. Its format is shown in Figure 9.

Although the size of this matrix may appear intimidating, the authors estimate that only 25-50 cells of the matrix will be needed for most projects.

88 Possible Environmental Elements



100 Possible Human Actions

Figure 9

Proposed Environmental Impact Matrix

The main matrix should be used in order to make sure no important interaction is missed, and then the matrix may be collapsed down to the rows and columns that are actually used.

Because short-term and long-term consequences of actions often differ, it should be made clear which time frame is being used in the matrix. The matrix is used by identifying and checking off actions involved in the project at the top of the matrix, then descending down each checked column to locate environmental effects. The authors advise the user to check off only the "first-order" effects, for the detail of the actions listed at the matrix top incorporates subsidiary actions of a major project.

After location of the cells identifying interactions, the magnitude and the importance of the interaction on the environment are rated on a scale of 1-10, and recorded in the cell. A hypothetical collapsed matrix and the notation system used are shown in Figure 10.

The impact matrix then serves as a basis for the next step:

7) Write a text, describing the assessment of impact.

The cells containing large magnitude and importance indices should be discussed here, as should those matrix columns and rows with many of the cells filled in. In addition, the rationale for the ratings of magnitude and importance should be explained.

After a thorough discussion of the impact and other relevant points, the authors arrive at the last step:

8) Write a summary and recommendations.

Another early environmental impact procedure was written at Battelle Columbus Laboratories for the Bureau of Reclamation in 1971. Entitled Design of an Environmental Evaluation System (Ira L. Whitman, et al., 1971), the procedure is designed to be used by the Bureau in evaluation of its projects. In structure, it is a hierarchical arrangement of elements

HUMAN ACTIONS		ENVIRONMENTAL ELEMENTS	
		II C.b	II D.f
		Surface Excavation	Mineral Processing
I A.2.d	Water Quality	2 / 2	1 / 1
I C.2.e	Camping & Hiking	2 / 4	N/A / N/A

CELL NOTATION

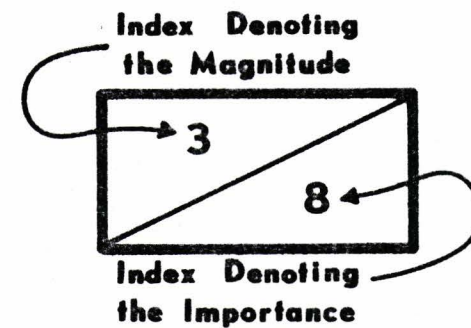


Figure 10
Environmental Impact Matrix for Project

similar to that used by Niemann and Miller in An Interstate Highway Corridor Selection Process and in EDAP. A diagram of the structure is shown in Figure 11. The four categories are those of Ecology, Environmental Pollution, Esthetics and Human Interest. These categories (and those elements lower in the hierarchy) were derived by an interdisciplinary team studying the operations of the Bureau of Reclamation, and a review of the literature in impact assessment.

Once the important elements were selected, a weighting system was designed to reflect the relative importance of each element on the total environmental impact. A total rating of 1000 points was first divided among the four major categories. Criteria for weight selection were:

- 1) scientific knowledge on the parameter's sensitivity to changes in the environment;
- 2) inclusiveness of the parameter in measuring environmental impacts; and
- 3) the relevance of the parameter to the projects of the Bureau of Reclamation.

Weights chosen for the four categories were: Ecology (315); Environmental Pollution (321); Esthetics (159), and Human Interest (205). Then those values were further subdivided in the same way for each of the successive components, parameters, and measurements.

The authors say that the weights should be constantly re-examined using groups of citizens and a modified Delphi feedback approach, but it seems possible that the weights could become institutionalized and inflexible under certain conditions. This, of course, would virtually invalidate the rest of the procedure, for decision-making is a composite of facts and values. Without the use of valid values, incorrect or inappropriate decisions are likely.

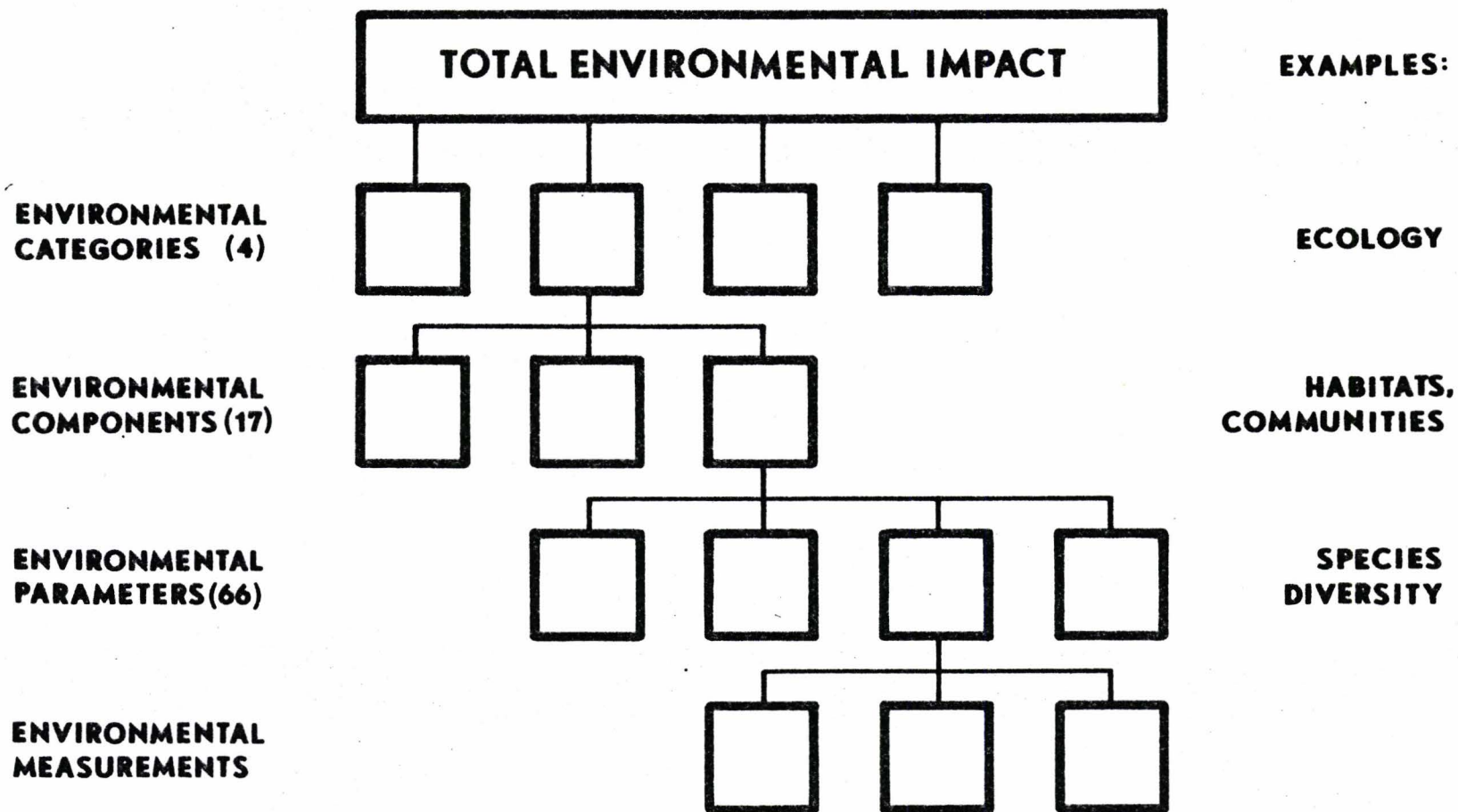


Figure 11
Hierarchy of Elements for Environmental Impact Analysis

With the framework set up, the method may be applied. A form showing the method of application is shown in Figure 12. For each parameter, and within its weight range, environmental quality is evaluated with and without the project. In the example, the rating for rare and endangered species is given 9 out of 16 points before the project, and decreases to 6 with the project, a change of -3. Similar calculations are made for each parameter, and the values are totaled and tabulated for each component and category.

Both the proposals for environmental impact analysis presented so far were prepared fairly soon after the adoption of the National Environmental Policy Act. Each was considered tentative by its authors. Other approaches have been prepared as the applications and requirements of NEPA have been clarified by the courts, and new knowledge about environmental interactions has been generated. An extremely interesting and extremely complex methodology has recently been proposed to integrate environmental knowledge. Entitled "An Information System for Environmental Planning" (Lyle and von Wodtke, 1974) the system analyzes the interactions of three factors: 1) location, 2) developmental actions, and 3) environmental effects.

The latter factor is presented in a most appropriate and impressive way: as flow diagrams detailing the interactions of a particular variable with the environment, at all energy levels and biospheres. This approach is in marked contrast to most methods that simply concern themselves with static condition lists. Variables described in this dynamic way included the flow of solar energy, water, and nutrients at a regional scale. Presumably other materials are available for additional variables and scales.

The location factor deals with the handling of data at four different scales: 1) regional, 2) planning unit (up to 100 square miles), 3) local, for ten square mile areas, and 4) the design level. The third factor considered, developmental actions, describes environmental modifications

Evaluation Team

Project Location _____
Project Name _____
Dates of Evaluation _____
Site Evaluated _____

Environmental Quality Units (EQU)



A. Species & Populations (144 EQU)

- | | | |
|---|----|----------------------------|
| 1 | 16 | Rare & Endangered Species |
| 2 | 16 | Productive Plant Species |
| 3 | 16 | Game Animals |
| 4 | 16 | Other Animals |
| 5 | 16 | Resident & Migratory Birds |
| 6 | 16 | Sport Fisheries |
| 7 | 16 | Commercial Fisheries |
| 8 | 16 | Pestilent Species |
| 9 | 16 | Parasites |

Subtotal - Species & Populations

B Habitats & Communities

-
- | Category | Value |
|-------------------|-------|
| Species Diversity | 48 |
| Food Chains | 24 |

etc.

VALUE IN EQU

[illegible]

Figure 12

A Partial Evaluation Format from the Environmental Evaluation System

that accompany development (Landform Alteration, Landform Stabilization, Modification of Vegetation, etc.) and describes existing methods used to accomplish the modification, lists the processes that will be affected, and characterizes the impact upon them.

These three factors are integrated by means of charts listing the interrelationships. Through a complex series of procedures, the materials may be used to generate a "suitability model" showing the areas most suitable for a given activity; an "environmental impact model" serving as a framework for an environmental impact statement; and a "best-action model" which proposes the development most environmentally sound. It is beyond the scope of this paper to discuss the details of this imposing structure, but the original work is highly recommended to anyone who deals with environmental effects.

As may be noted by the reader, it has not been possible to present an exhaustive report on all publications relevant to this forest roads topic. Hopefully, those that have been reviewed stimulated some thinking about the variables that are important in this work. For the many other works which were not discussed, on the following page is an index of the bibliography assembled for this study. Each author's name (or the work title if no author is given) is listed under a category name. Those interested in a particular category are directed to the names found below it, and then to the bibliography where the works are arranged alphabetically by author's last name. Each work was indexed only once under its major topic, but hopefully the index will still be useful.

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